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Watershed Physical Processes Research Unit  
National Sedimentation Laboratory  
Oxford, Mississippi

## STABILITY ANALYSIS OF THE BUTTAHATCHEE RIVER BASIN, MISSISSIPPI AND ALABAMA



By Natasha Pollen, Andrew Simon, Lauren Klimetz and Danny Klimetz

USDA-ARS National Sedimentation Laboratory Report Number 50

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# **STABILITY ANALYSIS OF THE BUTTAHATCHEE RIVER, MISSISSIPPI AND ALABAMA**

**Prepared by**

**U.S. Department of Agriculture – Agricultural Research Service  
National Sedimentation Laboratory  
*Watershed Physical Processes Research Unit***

**For**

**Mississippi Department of Environmental Quality**

**November 2005**





## **STABILITY ANALYSIS OF THE BUTTAHATCHEE RIVER, MISSISSIPPI AND ALABAMA**

ARS Designated Representative and Project Manager:

**Carlos V. Alonso**

Technical Direction, Data Analysis:

**Andrew Simon**

Report Preparation:

**Natasha Pollen, Andrew Simon, Lauren Klimetz and Danny Klimetz**

Mapping, GIS and Interactive CD:

**Danny Klimetz**

Field Operations and Database Management:

**Mark Griffith and Lauren Klimetz**

Field Data Collection and Data Processing:

**Mark Griffith, Natasha Pollen, Brian Bell, Lauren Klimetz, Danny Klimetz, and Lee  
Patterson**



## EXECUTIVE SUMMARY

The overall purpose of this study was to evaluate the stability of the Buttahatchee River and major tributaries, and to determine if observed instabilities were the result of localized or system-wide disturbances. Instabilities in the channel may lead to excessive sediment erosion and deposition, believed to have caused a decline in the mussel population throughout the river system. To determine the current stability conditions of the Buttahatchee River and the way the river's morphology has changed in the past 35 years, a combination of approaches were used. Current conditions were obtained using rapid geomorphic assessments (RGA's) and aerial reconnaissance, while historical conditions and changes in channel morphology were analyzed using time-series aerial photography and USGS gage data. To compliment the RGA analysis of current conditions on the Buttahatchee River, a bank stability model was used to identify critical conditions for stability at representative sites in each reach.

The Buttahtachee River is moderately unstable throughout the 172 km of river studied. RGA results showed that 91% (98 of 108 sites) of the sites visited were unstable to some degree. All of the RGA sites were either Stage V (unstable: aggradation with bank widening) or Stage VI (stable), indicating that no sites were actively incising. Of the unstable sites, all but one (D90), were considered to be moderately unstable (stability index of 10-20), with the remaining sites falling into the highly unstable category (stability index >20). Current conditions in the Buttahatchee River are typical of Stage V conditions where aggradation and channel widening are occurring as a response to energy changes that are propagating through the system in the river's attempt to reach a new quasi-equilibrium.

The channel is responding to a number of disturbances that have predominantly occurred in reach A, and have propagated upstream, and to other disturbances that are affecting reach D and are propagating downstream. The disturbances to reach A include "natural" and anthropogenic meander cutoffs, construction of the Tennessee-Tombigbee Waterway including impoundment of the Columbus pool, and gravel-mine capture and ponding. Disturbances in reach D are related to the delivery of excessive amounts of sediment to the reach due to land-use practices and the consequent streambank instability associated with bar growth and flow deflection.

Analysis of aerial photography showed that during the first three time periods of analysis (1958 to 1981, 1981 to 1992 and 1992 to 1999) there was a general attenuation in average bank-top widening rates moving upstream away from reach A, where most of the disturbances were concentrated. The exception to this trend is reach D, in which rapid rates of widening identified in the air photos are a result of channel migration related to excessive sediment emanating from logged areas, and the close proximity of some of these activities to the river in several locations.

The primary instability throughout the Buttahatchee River System is streambank erosion. The most critical areas are located in the lower half of reach A, between river kilometers (rkm) 85 -90), and between rkm 105 to 113, and 117 to 121 in reach D. Bank stability analyses provide quantitative information on the critical conditions for stability at representative sections in each of the reaches. These can be used to identify stable bank geometries.



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## LIST OF ABBREVIATIONS AND UNITS

$a$	Exponent assumed to equal 1.0
<b>BMP</b>	Best-Management Practice
<b>BST</b>	Borehole Shear Test device
$c'$	Effective cohesion, in kilopascals; kPa
$c_a$	Apparent cohesion, in kilopascals; kPa
<b>Concentration</b>	Milligrams per liter; mg/l
$D$	Characteristic particle diameter, in millimeters; mm
$D_{50}$	Median particle diameter, in millimeters; mm
$D_{75}$	Particle size of which 75 % of the material is smaller than, in millimeters; mm
$D_{90}$	Particle size of which 90 % of the material is smaller than, in millimeters; mm
$F$	Driving force acting on bank material, in Newtons; N
$F_s$	Factor of Safety, a ratio
$g$	Acceleration due to gravity, in meters per square second; $9.81 \text{ m/s}^2$
$k$	Erodibility coefficient in cubic meters per Newton second: $\text{m}^3/\text{N-s}$
<b>Load</b>	Calculated using a site specific power rating curve, in metric tonnes per day or year; T/d or T/y
$Q_{1.5}$	Discharge with a recurrence interval of 1.5 years, in cubic meters per second; cms
$R$	Hydraulic radius (area/wetted perimeter), or average flow depth, in meters; m
<b>RGA</b>	Rapid Geomorphic Assessment
<b>Rkm</b>	River kilometer
$S_b$	Bed slope, in meters per meter; m/m
$S_r$	Shear strength, in kilopascals; kPa
<b>TTW</b>	Tennessee-Tombigbee Waterway
<b>USGS</b>	United States Geologic Survey
$W$	Weight of failure block, in Newtons; N
<b>Yield</b>	Load divided by area, in metric tonnes per day per square kilometer; $\text{T/d/km}^2$ and in metric tonnes per year per square kilometer, $\text{T/y/km}^2$
$\beta$	Angle of the failure plane, in degrees
$\varepsilon$	Rate of scour, in meters per second; $\text{ms}^{-1}$
$\phi'$	The angle of internal friction, in degrees
$\phi^b$	The angle that describes the increase in shear strength due to an increase in matric suction, in degrees
$\gamma_w$	Unit weight of water, in Newtons per cubic meter; $9810 \text{ N/m}^3$
$\mu_a$	Soil pore air pressure, in kilopascals; kPa
$\mu_w$	Soil pore water pressure, in kilopascals; kPa
$\rho_s$	Sediment density, in kilograms per cubic meter; $2.65 \text{ kg/m}^3$
$\rho_w$	Water density, in kilograms per cubic meter; $1 \text{ kg/m}^3$
$\sigma$	Normal Stress, in kilopascals; kPa
$\tau^*$	Dimensionless critical shear stress
$\tau_c$	Critical shear stress, in Pascals; Pa
$\tau_e$	Excess shear stress, in Pascals; Pa
$\tau_o$	Average boundary shear stress, in Pascals; Pa
$\psi$	Matric suction, the difference between air pressure and water pressure ( $\mu_a - \mu_w$ ), in kilopascals, kPa



## 1. INTRODUCTION AND PROBLEM

Sediment is listed as one of the principle pollutants of surface waters in the United States by the 1996 National Water Quality Inventory (Section 305 (b) Report to Congress). Section 303 (d) of the Federal Clean Water Act requires each State in the U.S. to prepare a list of waters impaired by pollutants. Several reaches of the Mississippi portion of the Buttahatchee River (Figure 1) have been placed on the States' 303(d) list for impaired waters. Channel instabilities may lead to excessive sediment erosion and deposition. High levels of sediment have the potential to fill streambed niches, having detrimental impacts upon biotic populations and ecosystem diversity. There is particular interest in mussel populations along the Buttahatchee River, because the river is host to several different species of mussel, some of which are listed federally as endangered species and a decrease in the number of mussels has been recorded.

Heightened sediment loads and observed bank failures along reaches of the Buttahatchee River have led the Mississippi Department of Environmental Quality (MDEQ) to question whether these problems are localized, or whether they represent system-wide channel adjustments. In response to these concerns the USDA-ARS National Sedimentation Laboratory was asked to initiate a study to determine the magnitude and extent of channel instabilities in the Buttahatchee River System. Future efforts to improve water-quality along the Buttahatchee River may involve combinations of best-management practices (BMPs) that will rely heavily on identifying sources of eroded sediment. Localized channel-erosion problems by their very nature are easier to address than those that may affect much of the drainage network.



## 2. PURPOSE AND SCOPE

The overall purpose of this study was to evaluate the stability of the Buttahatchee River and major tributaries, and to determine if observed instabilities were the result of localized or system-wide disturbances. Specific objectives included:

1. Evaluate the magnitude and distribution of channel instabilities in the Buttahatchee River and major tributaries, Mississippi and Alabama;
2. Determine if observed and documented instabilities are the result of local problems or a system-wide disturbance(s);
3. Determine current channel dimensions and identify headcut locations;
4. Document amounts and rates of channel change, and sediment-transport rates along selected reaches;
5. Estimate sediment contributions from streamside gullies using historical aerial photographs;
6. Determine the characteristics and critical conditions for streambank stability in selected reaches, and
7. Provide a summary of stability conditions and general alternatives for potential stabilization.

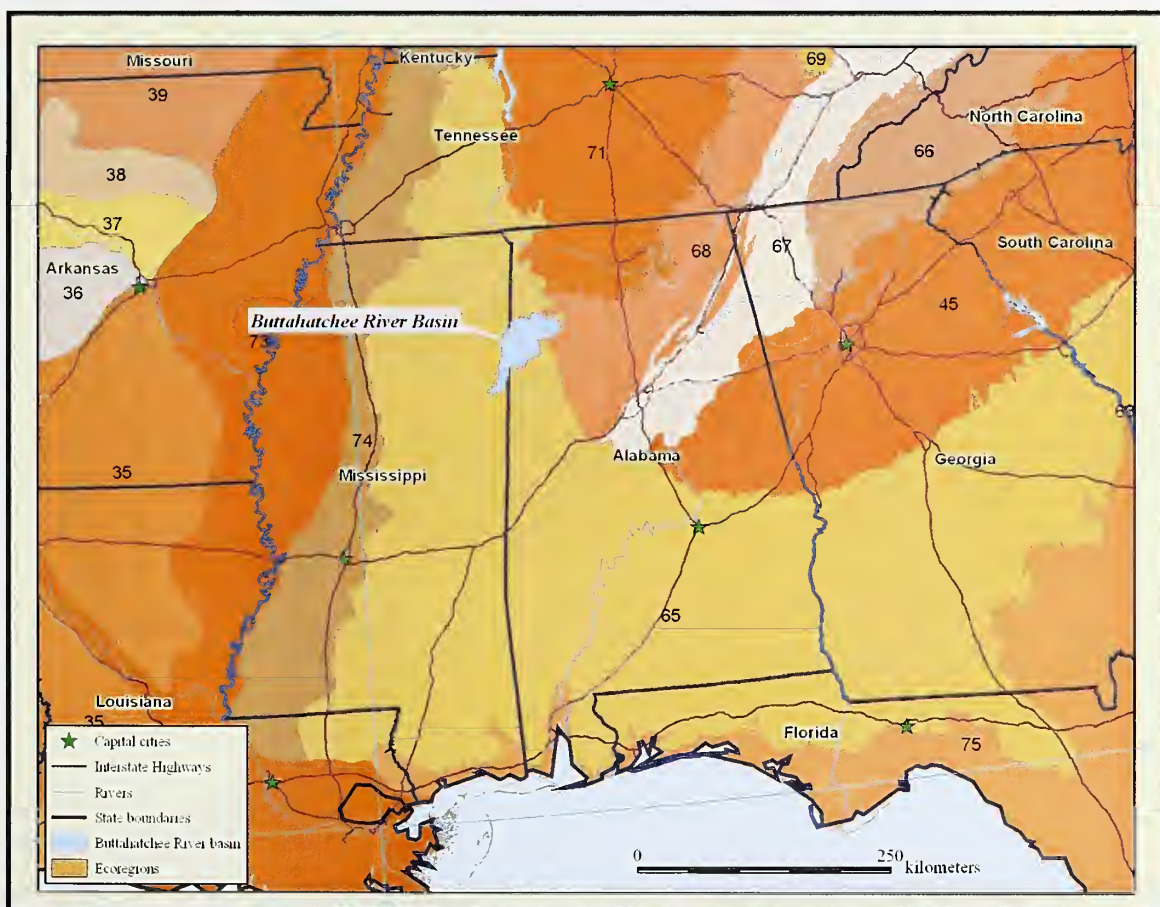
The geographic scope of the project is the entire Buttahatchee River Basin, with particular emphasis placed on the main stem and major tributary channels. Field data collection provided representations of current channel conditions, geometry and boundary sediments. Existing data concerning flow, sediment transport and channel geometry were also analyzed.



### 3. STUDY AREA

The Buttahatchee River is mainly located in the Southeastern Plains Ecoregion (#65) with upper reaches lying in the Southwestern Appalachians Ecoregion (#68). The river flows southwesterly from northwest Alabama to northeast Mississippi and drains into the Tennessee-Tombigbee Waterway near Columbus, Mississippi (Rivers of Alabama, 2001). The Buttahatchee River and its tributaries cover approximately 2250 square kilometers of Alabama and Mississippi (Figure 2). Major tributaries include Sipsey Creek, and Beaver Creek, among others. The study area along the main stem extends 172 kilometers from the mouth at the Tennessee-Tombigbee Waterway (rkm 172 following the current course of the river).

There are currently two real-time U.S. Geological Survey (USGS) gauging stations in operation on the Buttahatchee River, below Hamilton (02438000) and near Aberdeen (02439400). There have been eight USGS gauging stations collecting flow data in the Buttahatchee River Basin since 1939 (Table 1 and Figure 2). Unfortunately much of this flow data does not overlap and is short in length.

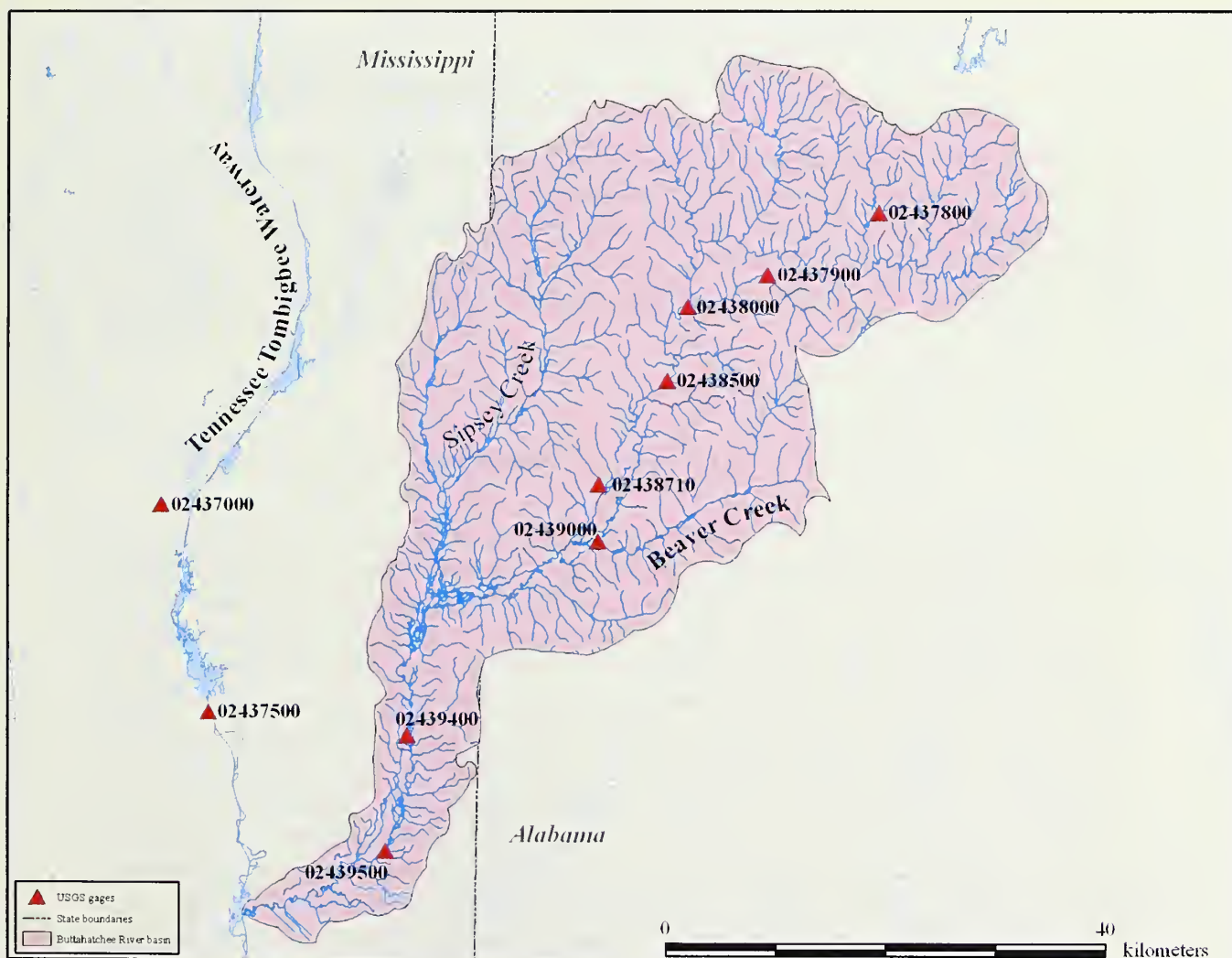


**Figure 1 – Location map of the Buttahatchee River Basin, in Mississippi and Alabama.**



**Table 1 – Period of record for stream gauges in the Buttahatchee River Basin. Real-time stations are highlighted yellow.**

State	Station number	Station location	Period of record
Alabama	02438700	Mill Creek near Detroit	1959 – 1967
Alabama	02438710	Spruiell Branch near Detroit	1980 – 1981
Alabama	02437900	Woods Creek near Hamilton	1959 – 1965
Alabama	02438000	Buttahatchee River below Hamilton	1951 – 2004
Alabama	02438500	Buttahatchee River near Hamilton	1941 – 1950
Alabama	02439000	Buttahatchee River near Sulligent	1939 – 1959
Mississippi	02439400	Buttahatchee River near Aberdeen	1966 – 2004
Mississippi	02439500	Buttahatchee River near Caledonia	1942 – 1951



**Figure 2 – Location of USGS gauging stations in the Buttahatchee River Basin and along the Tennessee-Tombigbee Waterway.**



## 4. METHODOLOGY

The methods used in this study combined four main research approaches:

1. Synthesis of existing data concerning flow, sediment transport and channel geometry. Data synthesis included existing surveys, aerial photography and GIS layers;
2. Field data collection on channel conditions, geometry, and characterization of boundary sediments; and
3. Use of field data to run the Bank Stability Model, a static model used to predict the relative stability of streambanks under different flow conditions and degrees of saturation.

### 4.1 Synthesis of Existing Data

There is a wide range of existing data available concerning the Buttahatchee River Basin. This data ranges from flow and suspended-sediment measurements obtained by the USGS, to historical maps, aerial photography and soil, land use and geology layers from government, academic or commercial sources. Additional data and information were also obtained from past reports related to mussel fauna and the construction of the Tennessee-Tombigbee Waterway.

#### 4.1.1 Analysis of Suspended-Sediment Data

Suspended-sediment data from the Buttahatchee River Basin were used to determine loads and yields (load per unit area) to be compared with regional values from Ecoregion 65. To accomplish this, a relation between flow and sediment concentration or load was established. This was carried out for the two USGS gauging stations with sufficient data listed in Table 2 (highlighted in yellow). For this study, data for suspended-sediment analysis covered a period of record spanning at least ten years and 30 or more suspended-sediment samples for sites in Ecoregion 65 from which to derive a transport relation. However, as there are such a low number of gauging stations in the Buttahatchee River Basin with sufficient data, requirements were lowered (Table 2). Instantaneous-concentration data combined with either an instantaneous flow value or flow data representing the value obtained from the stage-discharge relation at 15-minute intervals were used. Mean-daily values of both flow and sediment loads, which are readily available from the USGS, tend to be biased towards lower flows, particularly in flashy basins. To determine annual suspended-sediment loads, mean-daily flows were used in combination with the sediment-transport ratings to calculate mean-daily values. These values were then summed for each year of record to produce annual values.



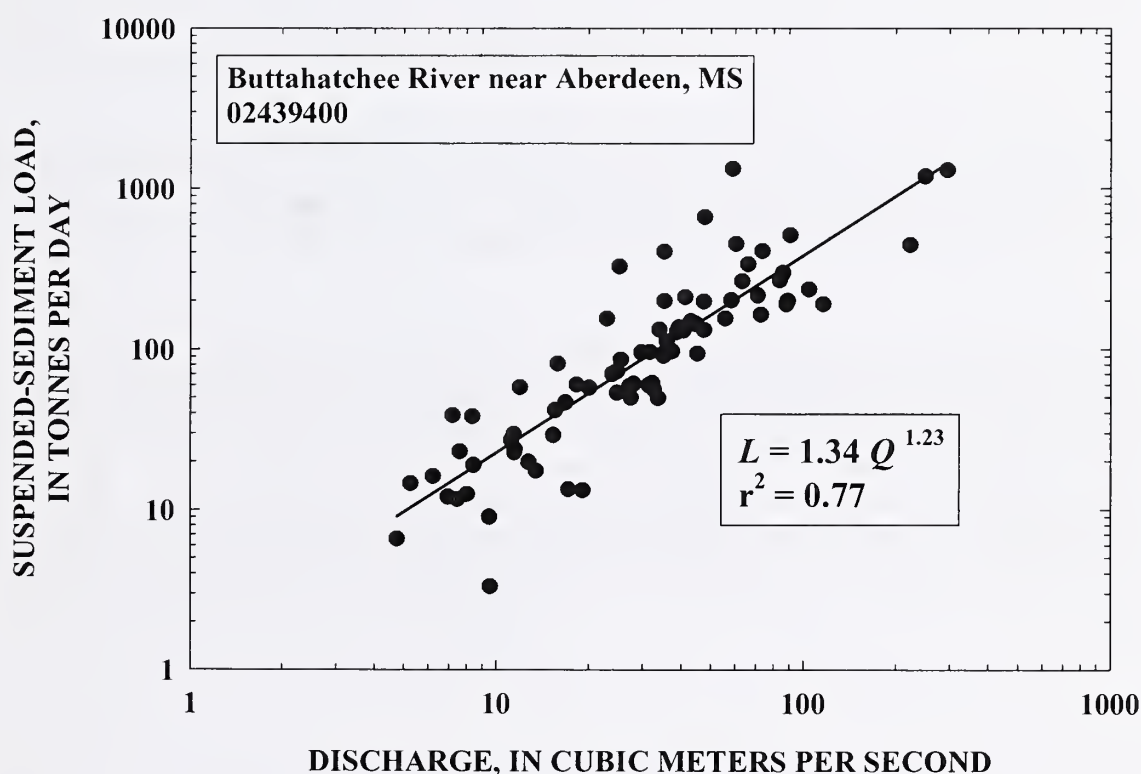
**Table 2 – Data acquisition summary for the Buttahatchee River Basin and the Tombigbee River. Highlighted in yellow are gauging stations for which all calculations were made.**

Gauge number	Gauge identification	State	Period of record	Drainage area in square kilometers	Instantaneous discharge and cross-sectional area data	Number of suspended sediment samples	Specific gage analysis	Mean daily data
02437800	Barn Creek near Hackleburg	AL	1959 - 1967	9.35	Yes	-	Yes	-
02438710	Spruiell Branch near Detroit	AL	1980 - 1981	7.38	-	-	-	-
02437900	Woods Creek near Hamilton	AL	1959 - 1965	37.0	Yes	4	Yes	Yes
02438000	Buttahatchee River below Hamilton	AL	1951 - 2004	717	Yes	9	Yes	Yes
02438500	Buttahatchee River near Hamilton	AL	1941 - 1950	792	Yes	-	Yes	Yes
02439000	Buttahatchee River near Sulligent	AL	1939 - 1959	1222	Yes	1	Yes	Yes
02439400	Buttahatchee River near Aberdeen	MS	1966 - 2004	2066	Yes	77	Yes	Yes
02439500	Buttahatchee River near Caledonia	MS	1942 - 1951	2152	Yes	-	Yes	Yes
02437500	Tombigbee River at Aberdeen	MS	1928 - 1983	5622	Yes	104	Yes	Yes
02437000	Tombigbee River near Amory	MS	1995 - 1997	4998	Yes	-	-	-
02441400	Tombigbee River near Columbus	MS	-	11528	Yes	35	-	-
02446500	Sipsey River near Elrod	AL	1928 - 2003	1367	Yes	-	Yes	-

Suspended-sediment transport relations are empirical representations of the sediment-transport regime at a given gauging station location, reflecting geomorphic, hydraulic and other watershed processes operating upstream. It is acknowledged that these power functions tend to mask specifics of governing sediment-transport processes, yet they still provide a useful foundation for calculating the amount of suspended sediment being transported over a broad range of flows (four or five orders of magnitude in many cases). Because the relations between water discharge and suspended-sediment load or concentration are approximate, typically high coefficients of determination between these variables (for example 0.90) may still have order-of-magnitude 95% prediction limits. This is generally caused by the natural variability of sediment-transport processes, rather than due to error in the suspended-sediment measurements. Predictions of the rate of sediment transport at a particular place and time are, therefore, not exact. However, prediction of mean transport rates over a suitably long period of time (represented by a transport relation) should have a higher degree of reliability if a dataset has been collected over the range of flows. Therefore, this is a valid means of describing and comparing the suspended-sediment transport regimes for streams from a broad range of environments.



Using storm event data concerning discharge and load, a suspended-sediment transport rating equation was developed (Porterfield, 1972; Glysson, 1987; Simon, 1989b) for sites in the Buttahatchee River Basin and throughout Ecoregion 65. Discharge was plotted against load in log-log space and a power function was obtained by regression (Figure 3). In studies carried out in other ecoregions across the United States, trends of these data (in log-log space) often increase linearly and then break off and increase more slowly at high discharges. Preliminary analyses show that although sand concentrations continue to increase with discharge, the silt-clay fraction attenuates, causing the transport relation to flatten (Kuhnle and Simon, 2000). This can also occur if a stream is sediment limited and loads attenuate at increasing discharges. Figure 3 shows that this attenuation did not occur and that one rating equation was able to fit the data rather well.



**Figure 3 – Rating relation for gauge 02439400: Buttahatchee River near Aberdeen, MS; Ecoregion 65.**

One of the approaches selected to describe suspended-sediment transport at a site is based on the concept of “effective discharge.” The effective discharge is that discharge, or range of discharges, that shape channels and perform the most geomorphic work (and thus transports the most sediment) over the long term (Leopold and Wolman, 1960; Wolman and Miller, 1960). As a result of this, the effective discharge can serve as a useful indicator of regional suspended-sediment transport conditions for “reference” and



impacted sites. In many parts of the United States, the effective discharge for suspended-sediment is approximately equal to the peak flow that occurs on average, about every 1.5 years ( $Q_{1.5}$ ; Simon *et al.*, 2004) and may be analogous to the bankfull discharge in stable streams.

#### 4.1.2 Calculating Load at the Effective Discharge

Calculating the effective discharge is a matter of integrating a flow-frequency curve with a sediment-transport rating to obtain the discharge (or range of discharges) that transports the most sediment over the long term. This involves a three-step process: (1) Construct a flow-frequency distribution; (2) Construct a sediment-transport rating relation; and (3) Integrate the two relations by multiplying the sediment-transport rate for a specific discharge class by that discharge. The discharge class with the maximum product is defined as the effective discharge (Andrews, 1980).

Using the annual-maximum peak-flow series for each of the sites with available data in the Buttahatchee River Basin, the  $Q_{1.5}$  was calculated from the log-Pearson Type III distribution. The example shown in Figure 4 is for the Buttahatchee River near Aberdeen, MS, where the  $Q_{1.5}$  was determined to be  $488 \text{ m}^3/\text{s}$  from the annual-maximum series.

The suspended-sediment load at the  $Q_{1.5}$  was obtained by using the transport rating developed for the site (Figure 3), the  $Q_{1.5}$  (Figure 4), and solving for the load. This rating equation was then used to calculate daily load values in tonnes per day from mean-daily discharge. The mean-daily loads were summed for each complete calendar year, providing a mean annual load (T/y). To normalize data for watersheds of different size, the sediment load was divided by drainage area providing calculations of mean annual sediment yield ( $\text{T/y/km}^2$ ). All rating relations were checked to be sure that the  $Q_{1.5}$  falls within the measured bounds of the data set.



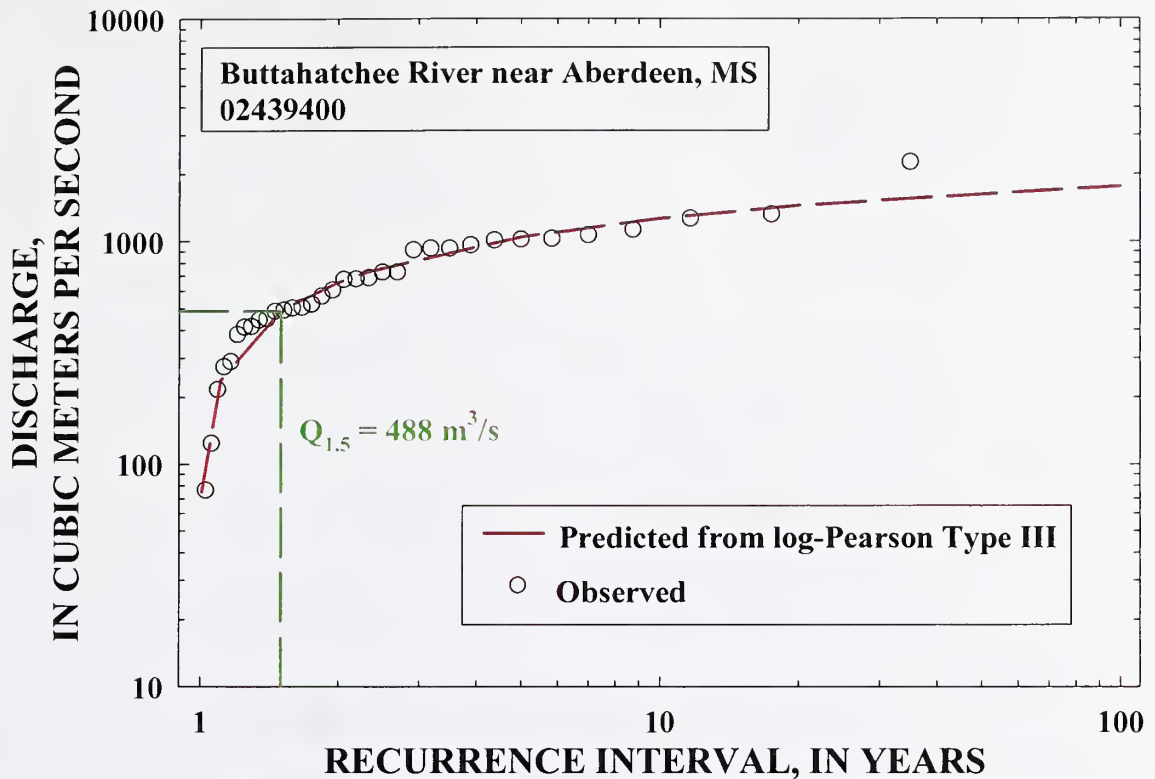


Figure 4 – Flood frequency distribution for the Buttahatchee River near Aberdeen, MS, as calculated from the annual maximum series, showing a  $Q_{1.5}$  of  $488 \text{ m}^3/\text{s}$  used to calculate sediment loads and yields at the effective discharge.

#### 4.1.3 Specific Gage Analysis using Water Surface Elevation

One way, in which to examine the stability of a channel at a given gage over a period of time is to determine the water-surface elevation of a given discharge with time to, this is termed specific gage analysis. Using gage height (m) and discharge data ( $\text{m}^3/\text{s}$ ) from USGS 9-207s for a given site, rating equations were developed for each year of data (Figure 5). The rating equations for each year were solved for a range of discharges (3, 10 and  $50 \text{ m}^3/\text{s}$ ) to calculate gage height at a specified discharge for any given year. This gage height was then added to the elevation of the gage from the USGS Site Inventory website (<http://waterdata.usgs.gov/nwis/si>) and a plot of water surface elevation over time created. The plot of water surface elevation over time enables trends in aggradation or degradation of the channel bed at low discharges and possible changes in stream banks at higher discharges.



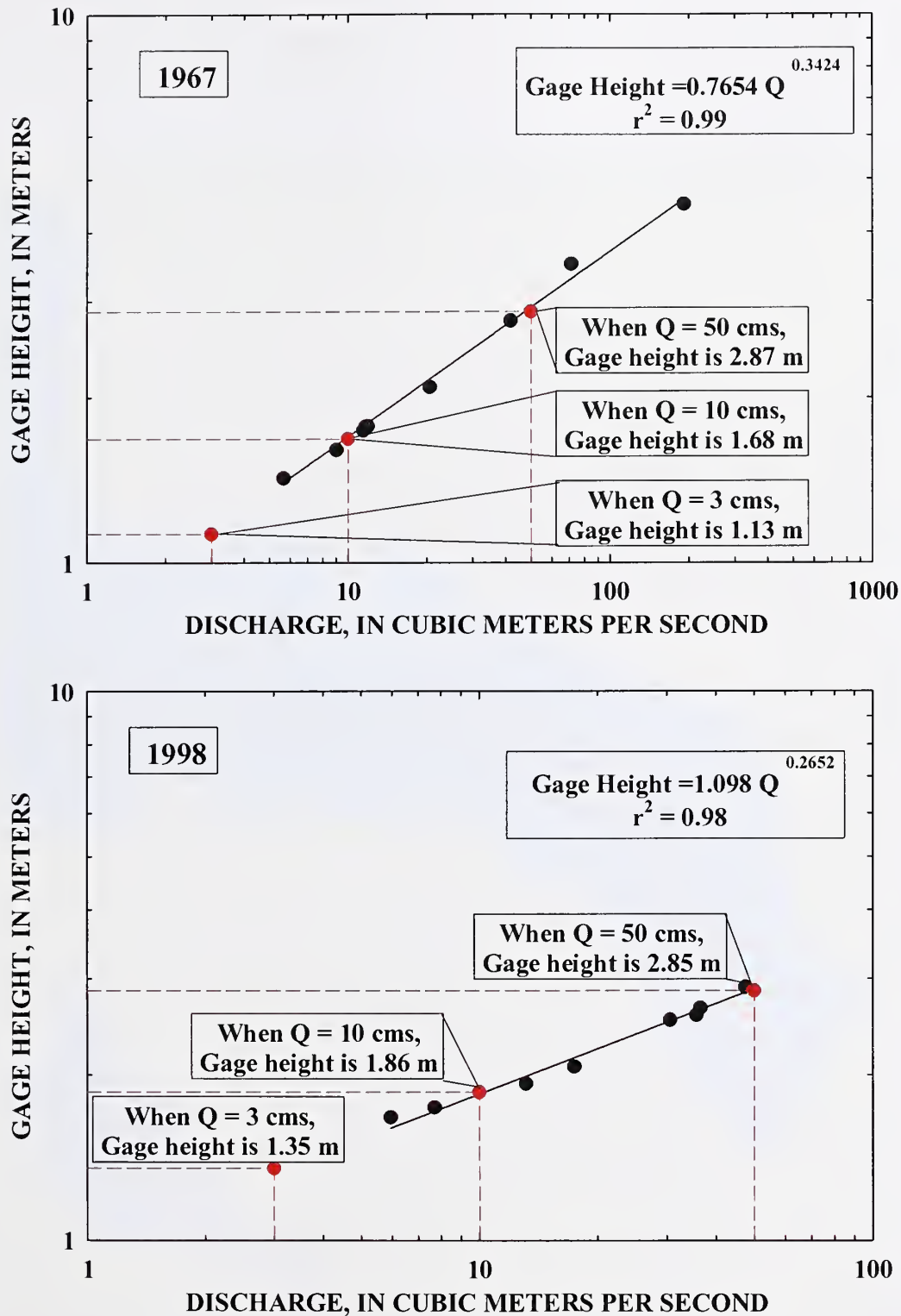


Figure 5 – Rating equation developed for Buttahatchee River near Aberdeen, 02439400 for 1967 and 1998 illustrating gage height differences over a range of flows over the course of 30 years.



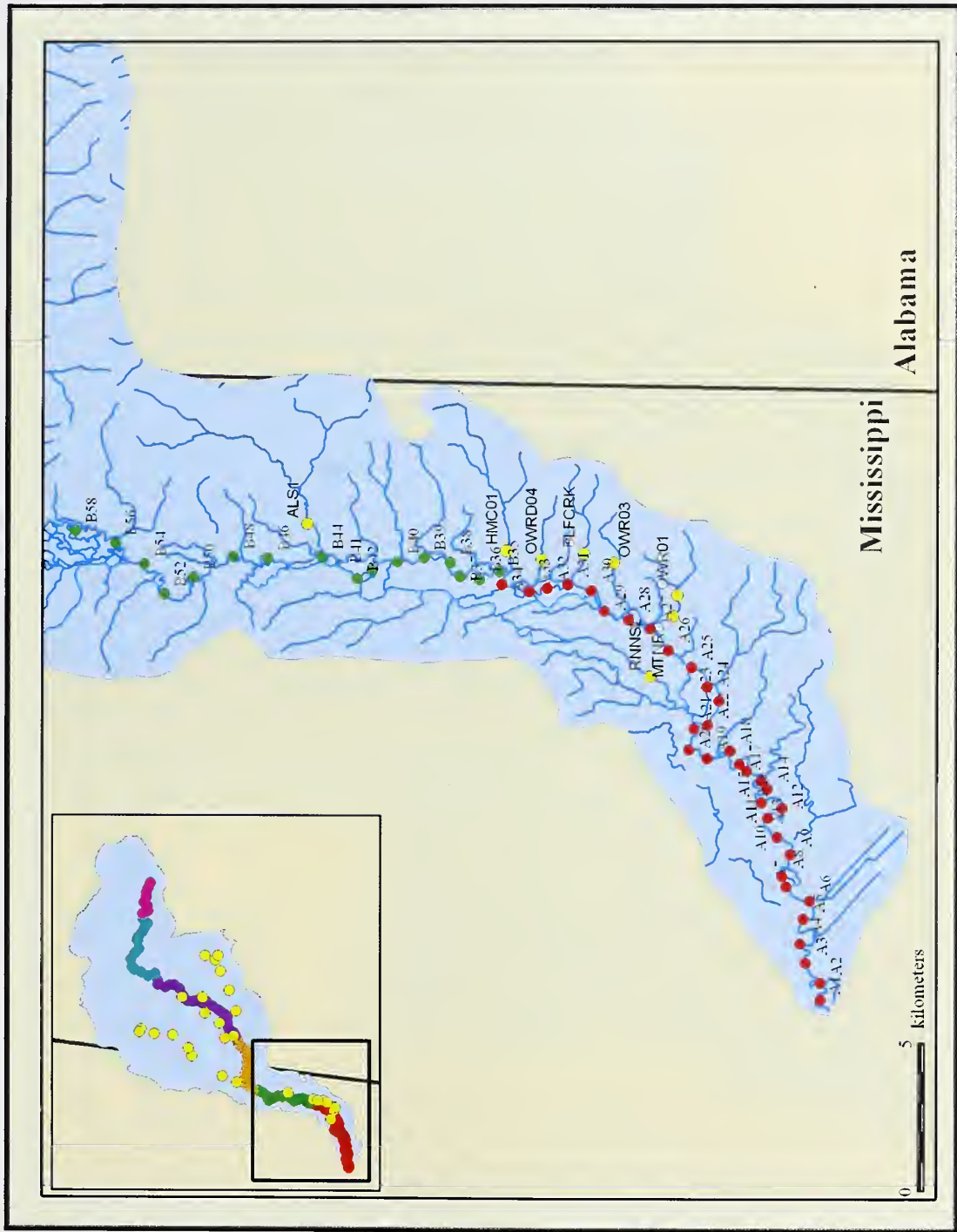


Figure 6 – Field sites located within reaches A and B along the Buttahatchee River and sites situated on tributaries.



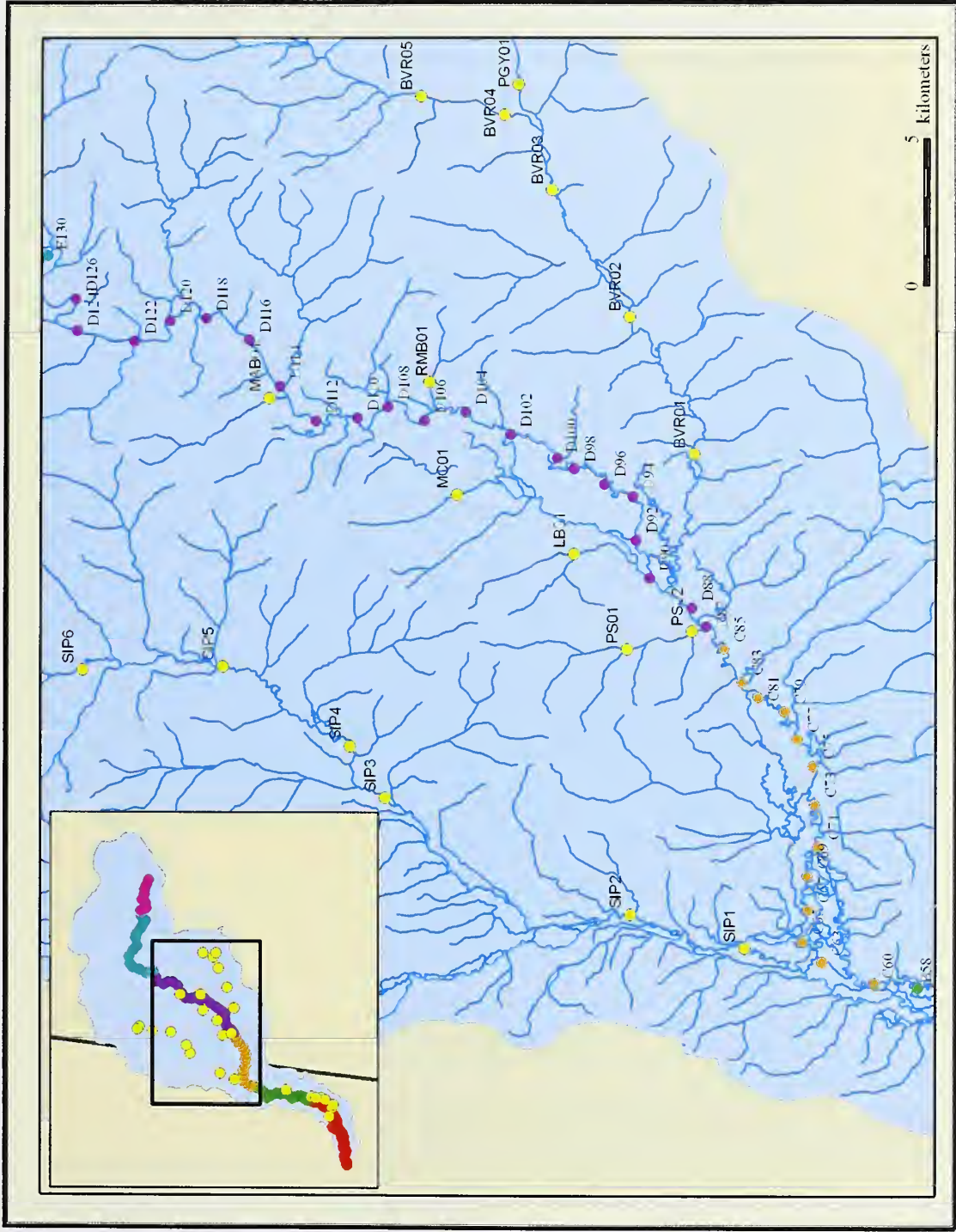


Figure 7 – Field sites within reaches C and D along the Buttahatchee River and sites located on tributaries.



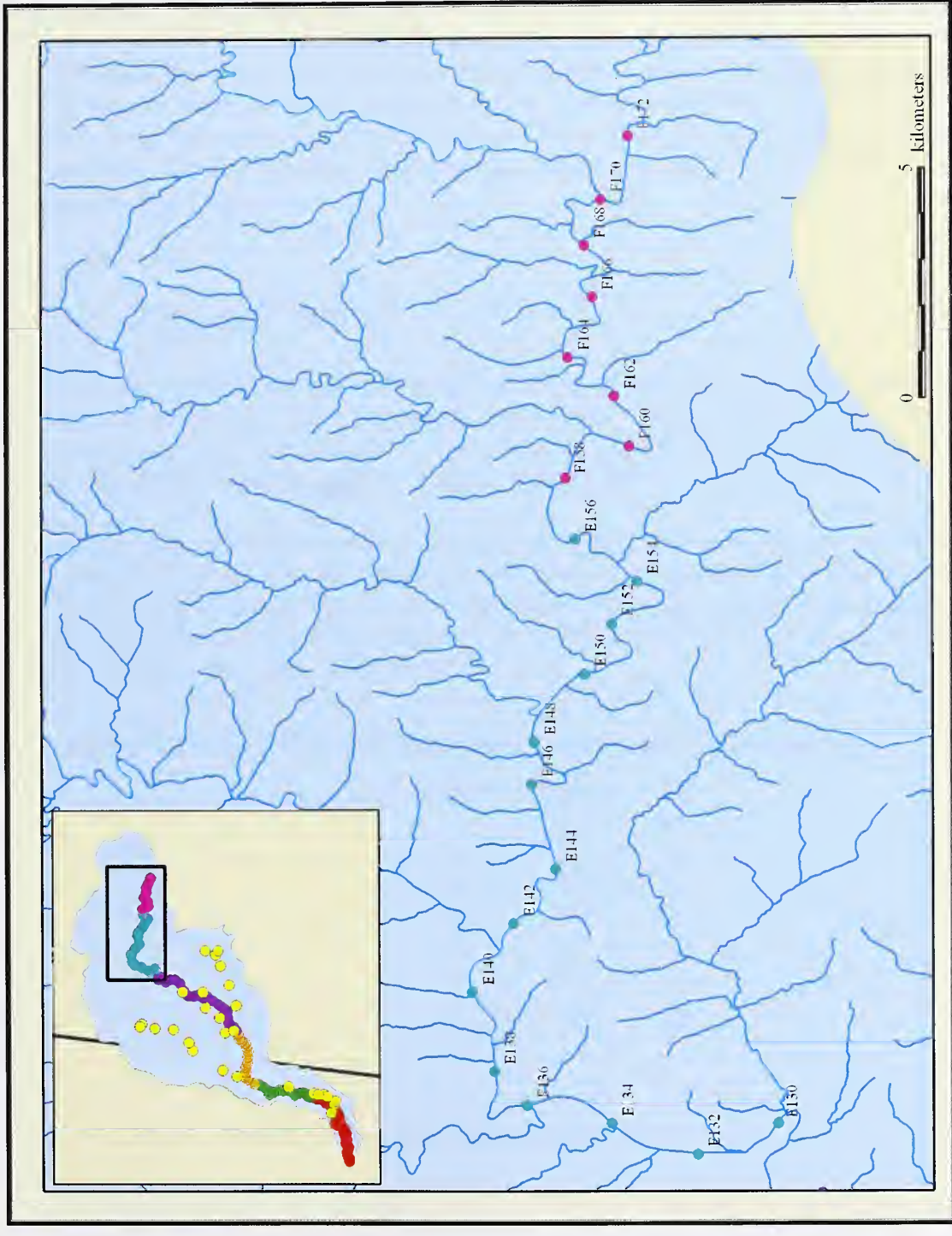


Figure 8 – Field Sites located in reaches E and F along the Buttahatchee River.



#### 4.1.4 Flow-frequency Analysis

To examine if changes along the Buttahatchee River are related to changes in flow magnitude and frequency, mean daily discharge data from the USGS was downloaded from <http://nwis.waterdata.usgs.gov/usa/nwis/discharge> for gages 02439400, Buttahatchee River near Aberdeen and 02438000 Buttahatchee River below Hamilton. Discharges over the given period of data were then binned into categories ranging from the 2 to 1050 cms (lowest and highest flows). Graphs were created of the data to examine variations in flow frequency that could be caused by both natural (climatic) and anthropogenic factors.

#### 4.2 Field Data Collection

Current stability conditions along the Buttahatchee River were examined using diagnostic criteria of contemporary geomorphic processes. These are called rapid geomorphic assessments (RGAs). Samples of bed and bank material were collected in some locations to characterize the resistance of streambeds and banks.

RGAs were conducted every river kilometer (rkm) to rkm 42 and every 2 rkm further upstream. Reaches were named between bridges. The intensity of data collection was greater below rkm 42 because this river reach. For ease in data management, analysis and interpretation, the Buttahatchee River main stem was split into six reaches, labeled A to F (Table 3 and Figures 6, 7 and 8):

**Table 3 - Reaches of the Buttahatchee River as described in this report.**

<b>Reach</b>	<b>From rkm</b>	<b>To rkm</b>
A	0	34
B	34	60
C	60	86
D	86	128
E	128	158
F	158	172

##### 4.2.1 Rapid Geomorphic Assessments: RGA's

Rivers are continually changing, active systems which can be considered in terms of stability. For the purpose of this study, stability is defined in geomorphic terms; that is, a dynamic equilibrium that can transport all of the sediment delivered to it from upstream without altering its dimensions over a period of years. That is not to say that the stream



is static but that the short-term, local processes of scour and fill, erosion and deposition, are balanced through a reach such that the stream does not widen, narrow, degrade or aggrade.

A Rapid Geomorphic Assessment (RGA) was carried out at each site using the channel-stability ranking scheme (Figure 6) to evaluate channel-stability conditions and stage of channel evolution of a particular reach. RGAs utilize diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities through a series of nine questions. Granted, evaluations of this sort do not include an evaluation of watershed or upland conditions; however, stream channels act as conduits for energy, flow and materials as they move through the watershed and will reflect a balance or imbalance in the delivery of water and sediment. RGAs provide an efficient method of assessing in-stream geomorphic conditions, enabling the rapid characterization and stability of long reaches of channel systems.

The RGA procedure consists of five steps to be completed on site:

1. Determine the extent of the 'reach'. The 'reach' is described as the length of channel covering 6-20 channel widths, thus is scale dependent and should cover at least two pool-riffle sequences;
2. Take photographs looking upstream, downstream and across the reach; for quality assurance and quality control purposes. Photographs are used with RGA forms to review the field evaluation;
3. Make observations of channel conditions and diagnostic criteria listed on the channel-stability ranking scheme;
4. Sample bed material;
5. Perform a survey of the thalweg, or water surface if the water is too deep to wade. Bed or water surface slope is then calculated over at least two pool-riffle sequences. Because of excessive flow depths and difficulties with access, surveys were not conducted.

#### **4.2.2 Channel-Stability Index**

A field form containing nine criteria (Figure 9) was used to record observations of geomorphic conditions during RGAs. Each criterion was ranked from zero to four and all values summed to provide an index of relative channel stability. The higher the number the greater the instability: sites with values greater than 20 exhibit considerable instability; stable sites generally rank 10 or less. Intermediate values denote reaches of moderate instability. However, rankings are not weighted, thus a site ranked 20 is not twice as unstable as a site ranked 10.



## CHANNEL-STABILITY RANKING SCHEME

River _____			Site Identifier _____		
Date _____	Time _____	Crew _____	Samples Taken _____		

Pictures (circle)	U/S	D/S	X-section	Slope _____	Pattern:	Meandering Straight Braided
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1. Primary bed material
 

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay	
0	1	2	3	4	
2. Bed/bank protection
 

Yes	No	(with)	1 bank	2 banks	
			protected		
0	1		2	3	
3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)
 

0-10%	11-25%	26-50%	51-75%	76-100%	
4	3	2	1	0	
4. Degree of constriction (Relative decrease in top-bank width from up to downstream)
 

0-10%	11-25%	26-50%	51-75%	76-100%	
0	1	2	3	4	
5. Stream bank erosion (Each bank)
 

	None	Fluvial	Mass wasting (failures)	
Left	0	1	2	
Right	0	1	2	
6. Stream bank instability (Percent of each bank failing)
 

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	0	0.5	1	1.5	2	
Right	0	0.5	1	1.5	2	
7. Established riparian woody-vegetative cover (Each bank)
 

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	
Right	2	1.5	1	0.5	0	
8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)
 

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	
Right	2	1.5	1	0.5	0	
9. Stage of channel evolution
 

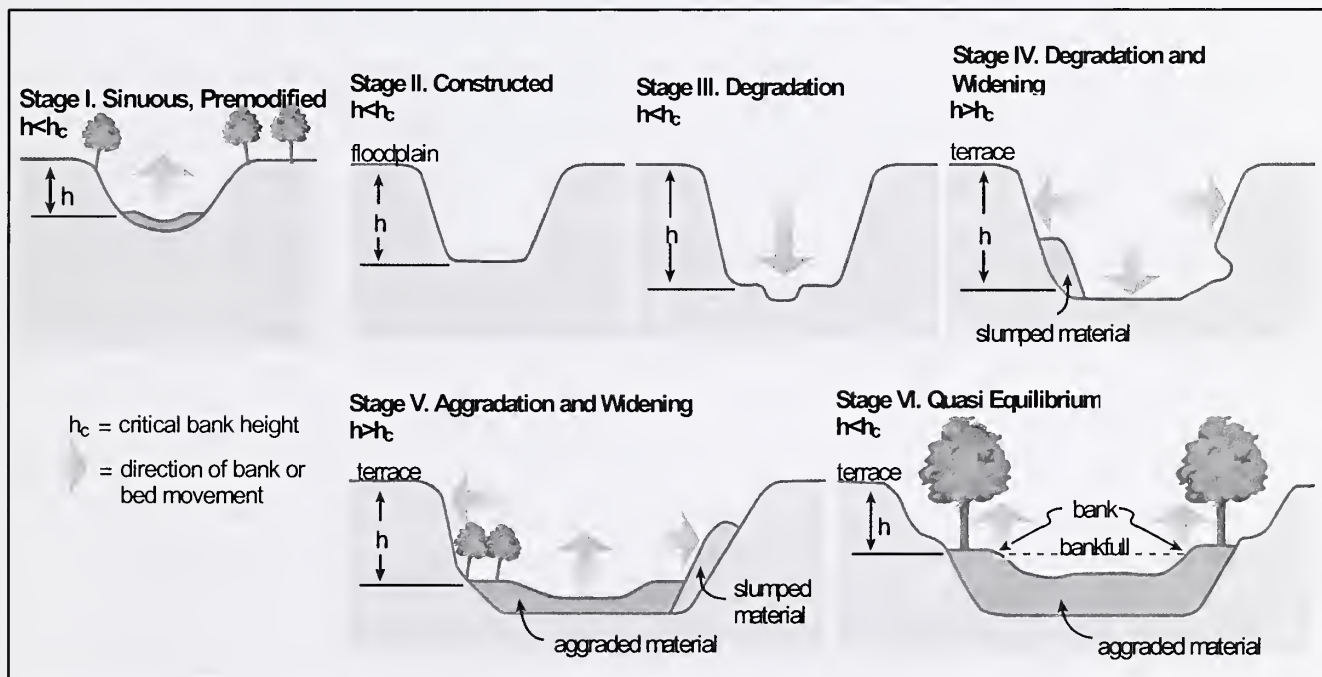
I	II	III	IV	V	VI	
0	1	2	4	3	1.5	

**Figure 9 – Channel stability ranking scheme used to conduct rapid geomorphic assessments (RGAs). The channel stability index is the sum of the values obtained for the nine criteria.**



### 4.2.3 Stages of Channel Evolution

The channel evolution framework set out by Simon and Hupp (1986) is used to assess the spatial and temporal aspects of channel adjustment processes of a channel reach (Figure 10; Table 4). With stages of channel evolution tied to discrete channel processes and not strictly to specific channel shapes, they have been successfully used to describe systematic channel-adjustment processes over time and space in diverse environments, subject to various disturbances such as stream response to: channelization in the Southeast US Coastal Plain (Simon, 1994); volcanic eruptions in the Cascade Mountains (Simon, 1999); and dams in Tuscany, Italy (Rinaldi and Simon, 1998). Because the stages of channel evolution represent shifts in dominant channel processes, they are systematically related to suspended-sediment and bed-material discharge (Simon, 1989b; Kuhnle and Simon, 2000), fish-community structure, rates of channel widening (Simon and Hupp, 1992), and the density and distribution of woody-riparian vegetation (Hupp, 1992).



**Figure 10 – Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989a) identifying Stages I and VI as “reference” conditions.**

An advantage of a process-based channel-evolution scheme is that Stages I and VI represent true “reference” or stable conditions. In some cases, such as in the Midwestern United States where land clearing activities near the turn of the 20<sup>th</sup> Century caused massive changes in rainfall-runoff relations and land use, channels are unlikely to recover to Stage I, pre-modified conditions. Stage VI, a re-stabilized condition, is a much more likely target under present regional land use and altered hydrologic regimes (Simon and Rinaldi, 2000) and can be used as a “reference” condition. Stage VI streams can be characterized as a ‘channel-within-a-channel’, where the previous floodplain surface is



less frequently inundated and can be described as a terrace. This morphology is typical of recovering and re-stabilized stream systems following incision. In pristine areas, where disturbances have not occurred or where they are far less severe, Stage I conditions can be appropriate as a reference.

**Table 4 - Summary of conditions to be expected at each stage of channel evolution**

Stage	Descriptive Summary
I	<i>Pre-modified</i> – Stable bank conditions, no mass wasting, small, low angle bank slopes. Established woody vegetation, convex upper bank, concave lower bank.
II	<i>Constructed</i> – Artificial reshaping of existing banks. Vegetation often removed, banks steepened, heightened and made linear.
III	<i>Degradation</i> – Lowering of channel bed and consequent increase of bank heights. Incision without widening. Bank toe material removed causing an increase in bank angle.
IV	<i>Threshold</i> – Degradation and basal erosion. Incision and active channel widening. Mass wasting from banks and excessive undercutting. Leaning and fallen vegetation. Vertical face may be present.
V	<i>Aggradation</i> – Deposition of material on bed, often sand. Widening of channel through bank retreat; no incision. Concave bank profile. Filled material re-worked and deposited. May see floodplain terraces. Channel follows a meandering course.
VI	<i>Restabilization</i> – Reduction in bank heights, aggradation of the channel bed. Deposition on the upper bank therefore visibly buried vegetation. Convex shape. May see floodplain terraces.

#### 4.2.4 Bed-Material Conditions

As part of each RGA, bed material was characterized. If the bed material was dominated by gravels (2.00 mm or greater) or coarser fractions, a particle count was carried out. For a particle count, the intermediate axis of one hundred particles across the channel was measured, in order to represent a range of different particle sizes found across the width of the bed. If 16 % of the measured particles have a median diameter of less than 2 mm, a bulk particle-size sample of 100 g or greater was collected from the left, middle and right parts of the channel bed. This bulk sample was sieved to half-Phi intervals. Particle size data were combined with particle count data to give percentiles of class sizes and values for commonly used metrics such as the median particle size. If the bed material was dominated by fines, only a bulk sample was taken.

Carrying out particle counts across the width of the channel and taking bulk samples proved difficult on certain reaches of the Buttahatchee River due to the depth and swiftness of water. In such cases where it was not possible to collect a sample or count particles, bed material composition was determined in the field. Mean values were calculated from upper and lower boundaries of a given size class. In many of the lower reaches, for example, the meandering channel rendered it impossible to wade across the



channel reaching the bed at all times to collect a stone to measure. In these cases it was determined that the bed material was gravel and a mean  $D_{50}$  diameter of 11.3 mm calculated (the upper and lower boundaries of the gravel size class are 64.0 and 2.00 mm respectively). For sand, 0.355 mm was the value used (upper and lower boundaries 2.00 and 0.063 mm). In rare cases where bedrock was found as the dominating bed material, a  $D_{50}$  value of 5000 mm was used.

A cemented gravel bed material, found in some of the lower reaches of the Buttahatchee River, suggests a relatively stable bed in these locations. Such cemented gravels were found to be black in color, again suggesting a lack of movement and stability. With resistant streambeds such as gravel or bedrock, channel adjustments to a disturbance are likely to involve bank erosion. In upper reaches there were also intermittent sections of bedrock where no vertical erosion could occur and no deposition was observed.

#### 4.2.5 Geotechnical Data Collection – Borehole Shear Tests

Representative sites were chosen in five of the reaches (Table 5; geotechnical data were not collected in reach F because bank and bed material was bedrock). To simulate bank-stability conditions along various reaches of the Buttahatchee River using the Bank Stability and Toe Erosion Model, the shear strength of the banks were characterized. Data required for model use included bulk unit weight of the bank materials, shear strength (cohesion and friction angle) and bank geometry. The streambanks of the Buttahatchee River were found to be predominantly alluvial, with layers of sand and gravel throughout (gravel content increased with depth in most cases). In addition, information on the erodibility of the bank toe was obtained. This consisted of a particle-size sample if the material was non-cohesive (sand or gravel) or with a jet-test device (Hanson, 1990) if the material was cohesive. As each of the intensive field sites had sand-gravel bank toe material, no jet testing was carried out. A complete survey of a representative cross-section was conducted.

**Table 5 – Locations of representative sites within each reach where geotechnical properties of the bank were measured.**

Reach	Extent of reach (rkm)	Location of geotechnical site (rkm)
A	0 – 34	10
		28
B	34 – 60	42
C	60 – 86	71
D	86 – 128	88
E	128 – 158	129
		157.5



Analyzing streambank stability is a matter of characterizing the gravitational forces acting on the bank and the geotechnical strength of the *in situ* bank material. Field data are required to quantify those parameters controlling this balance between force and resistance. If we initially envision a channel deepened by bed degradation in which the streambanks have not yet begun to fail, the gravitational force acting on the bank cannot overcome the resistance (shear strength) of the *in situ* bank material. Shear strength is a combination of frictional forces represented by the angle of internal friction ( $\phi'$ ), and effective cohesion ( $c'$ ). Positive pore-water pressures in the bank (below the water table) serve to reduce the frictional component of shear strength. Negative pore-water pressures occur in the zone above the water table and serve to increase apparent cohesion and shear strength. A factor of safety ( $F_s$ ) is expressed then as the ratio between the resisting and driving forces. A value of unity indicates the critical case and imminent failure.

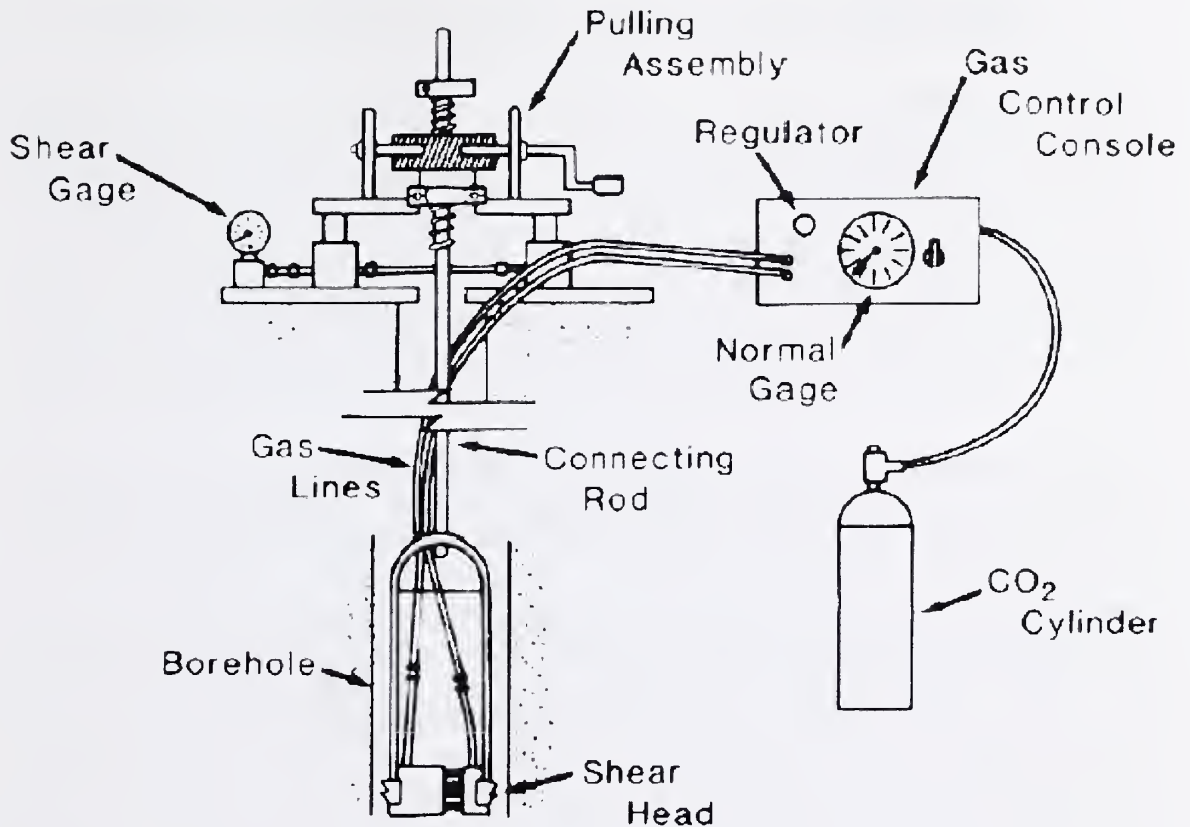
To aid in quantifying the driving, gravitational forces at each testing depth, a small core of known volume was removed, sealed and returned to the laboratory. The samples were weighed, dried and weighed again to obtain values of bulk unit weight, required for analysis of streambank stability.

To properly determine the resistance of cohesive materials to erosion by mass movement, data must be acquired on those characteristics that control shear strength; that is cohesion, angle of internal friction, pore-water pressure, and bulk unit weight. Cohesion and friction angle data can be obtained from standard laboratory testing (triaxial shear or unconfined compression tests), or by *in-situ* testing with a borehole shear-test (BST) device (Lohnes and Handy 1968; Thorne *et al.* 1981; Little *et al.* 1982; Lutenegeger and Hallberg 1981). The BST provides direct, drained shear-strength tests on the walls of a borehole (Figure 11).

Advantages of the instrument include:

1. The test is performed *in situ* and testing is, therefore, performed on undisturbed material.
2. Cohesion and friction angle are evaluated separately with the cohesion value representing apparent cohesion ( $c_a$ ). Effective cohesion ( $c'$ ) is then obtained by adjusting  $c_a$  according to measured pore-water pressure and  $\phi^b$ .
3. A number of separate trials are run at the same sample depth to produce single values of cohesion and friction angle based on a standard Mohr-Coulomb failure envelope.
4. Data and results obtained from the instrument are plotted and calculated on site, allowing for repetition if results are unreasonable; and
5. Tests can be carried out at various depths in the bank to locate weak strata (Thorne *et al.* 1981).





**Figure 11 – Schematic representation of borehole shear tester (BST) used to determine cohesive and frictional strengths of in situ streambank materials. Modified from Thorne et al. (1981).**



### 4.3 Quantifying streambank stability – The Bank Stability Model (BSM)

Conceptual models of bank retreat and the delivery of bank sediments to the flow emphasize the importance of interactions between hydraulic forces acting at the bed and bank toe, and gravitational forces acting on *in situ* bank materials (Carson and Kirkby, 1972; Thorne, 1982; Simon *et al.*, 1991; Langendoen, 2000). Failure occurs when erosion of the bank toe and the channel bed adjacent to the bank increase the height and angle of the bank to the point that gravitational forces exceed the shear strength of the bank material. After failure, failed bank materials may be delivered directly to the flow and deposited as bed material, dispersed as wash load, or deposited along the toe of the bank as intact blocks, or as smaller, dispersed aggregates (Simon *et al.*, 1991).

#### ***Hydraulic Forces and Resistance: Calculating Bank-Toe Erosion by Hydraulic Shear***

The magnitude of bank-toe erosion and bank steepening by hydraulic forces is calculated using a bank-toe erosion algorithm incorporated into the Bank-Stability Model (Simon *et al.*, 1999) to form the Bank Stability and Toe Erosion Model (BSTEM, Simon and Pollen, In Press). The algorithm calculates the hydraulic forces acting on the bank face for a particular flow event. Flows are discretized as simple, rectangular hydrographs with the user specifying flow depth, channel gradient and the duration of the flow. The boundary shear stress exerted by the flow on each node, is determined by dividing the flow area at a cross section into segments that are affected only by the roughness on the bank or on the bed and then further subdividing to determine the flow area affected by the roughness on each node. The line dividing the bed- and bank-affected segments is assumed to bisect the average bank angle and the average bank toe angle. The hydraulic radius of the flow on this segment is the area of the segment ( $A$ ) divided by the wetted perimeter of the segment ( $P_n$ ), and  $S$  is the channel slope. Fluid shear stresses along the dividing lines are neglected when determining the wetted perimeter. An average erosion distance is computed by comparing the boundary shear stress with critical shear stress and erodibility for each node for the specified duration of the peak.

In the toe erosion algorithm the rate of scour  $\varepsilon$  ( $\text{ms}^{-1}$ ) is assumed to be proportional to the shear stress in excess of a critical shear stress and is expressed as:

$$\varepsilon = k (\tau_o - \tau_c)^a \quad (1a)$$

where  $k$  = erodibility coefficient ( $\text{m}^3/\text{N-s}$ ),  $\tau_o$  = average boundary shear stress (Pa),  $\tau_c$  = critical shear stress, and  $a$  = exponent assumed to equal 1.0. The quantity  $(\tau_o - \tau_c)$  = excess shear stress (Pa).

Average boundary shear stress, representing the stress applied by flowing water along the edge of the bank is calculated from channel geometry and stage data collected at the sites as:

$$\tau_o = \gamma R S \quad (1b)$$



where  $\gamma$  = unit weight of water ( $\text{N/m}^3$ ),  $R$  = hydraulic radius (m), and  $S$  is channel gradient (m/m). An inverse relation between  $\tau_c$  and  $k$  occurs when soils exhibiting a low  $\tau_c$  have a high  $k$  or when soils having a high  $\tau_c$  have a low  $k$ .

Erosion of bank-toe materials can then be calculated using equations 1a and 1b. Critical shear stress of these types of materials can then be calculated using conventional (Shields-type) techniques as a function of particle size and weight.

### ***Geotechnical Forces and Resistance: Calculating Mass-Bank Stability***

The BSM performs stability analysis of planar-slip failures and accounts for the important driving and resisting forces that control bank stability. Bank geometry, soil shear-strength (effective cohesion,  $c'$ , and angle of internal friction,  $\phi'$ ), pore-water pressure, confining pressure, and mechanical and hydrologic effects of riparian vegetation are used to numerically determine the critical conditions for bank stability.

The BSM (Simon *et al.*, 1999) was developed for use with multi-layered banks with complex geometries. The model accounts for the geotechnical resisting forces by using the failure criterion of the Mohr-Coulomb equation for the saturated part of the failure surface:

$$S_r = c' + (\sigma - \mu) \tan \phi' \quad (2)$$

where  $\mu$  is the pore pressure and  $\phi'$  is the angle of internal friction. For the unsaturated part of the failure surface the criterion as modified by Fredlund *et al.* (1978) is used:

$$S_r = c' + (\sigma - \mu_a) \tan \phi' + (\mu_a - \mu_w) \tan \phi^b \quad (2a)$$

where  $S_r$  is shear strength (kPa),  $c'$  is effective cohesion (kPa),  $\sigma$  is normal stress (kPa),  $\mu_a$  is pore air pressure (kPa),  $\mu_w$  is pore-water pressure (kPa),  $(\mu_a - \mu_w)$  is matric suction, or negative pore-water pressure (kPa), and  $\tan \phi^b$  is the rate of increase in shear strength with increasing matric suction. The quantity  $(\mu_a - \mu_w) \tan \phi^b$  represents the additional strength provided by matric suction along the unsaturated part of the failure plane and is reflected in the apparent or total cohesion ( $c_a$ ) term although this does not signify that matric suction is a true form of cohesion (Fredlund and Rahardjo, 1993):

$$c_a = c' + (\mu_a - \mu_w) \tan \phi^b \quad (3)$$

The geotechnical driving force is given by the term:

$$F = W \sin \beta \quad (4)$$

where,  $F$  = driving force acting on bank material (N),  $W$  = weight of failure block (N), and  $\beta$  = angle of the failure plane (degrees).



## 5. RESULTS

To determine the current stability conditions of the Buttahatchee River and the way the river's morphology has changed in the past 35 years, a combination of approaches were used. Current conditions were obtained from RGA's and aerial reconnaissance, while historical conditions and changes in channel morphology were analyzed using time-series aerial photography and USGS gage data. To compliment the RGA analysis of current conditions on the Buttahatchee River, a bank stability model was used to identify critical conditions for stability at representative sections of each of the six reaches (A to F) identified in this report.

### 5.1 Current Geomorphic Conditions

RGA results showed that 91% (98 of 108 sites) of the sites visited along the 172 km of channel studied, were unstable to some degree. All of the RGA sites were either Stage V (unstable: aggradation with bank widening) or Stage VI (stable), indicating that no sites were actively incising. Of the unstable sites, all but one were considered to be moderately unstable (stability index of 10-20), with the remaining site falling into the highly unstable category (stability index >20) (Table 6):

**Table 6 – Summary of channel stability indices obtained from RGA's for each reach of the Buttahatchee River studied, and two of its tributaries.**

Reach	Mean stability index	Frequency of occurrence		
		0 to 10	10 to 20	>20
<b>A</b>	11.1	9	25	0
<b>B</b>	14.4	0	16	0
<b>C</b>	13.8	1	12	0
<b>D</b>	16.4	0	19	1
<b>E</b>	10.2	8	8	0
<b>F</b>	13.1	1	7	0
<b>Sipsey River</b>	9.1	5	2	0
<b>Pine Springs Tributary</b>	6.3	2	0	0

To understand fully the causes and extent of instability along the Buttahatchee River, we must first study past changes in channel morphology, and understand natural and anthropogenic disturbances that have affected the river. The following sections describe the channel changes that could be determined from air photo analysis and gage records. Interpretation of past changes to channel morphology are crucial if we are to understand the current conditions of the Buttahatchee River, and how they might continue to change in the future. However, it is important to point out that we were unable to obtain



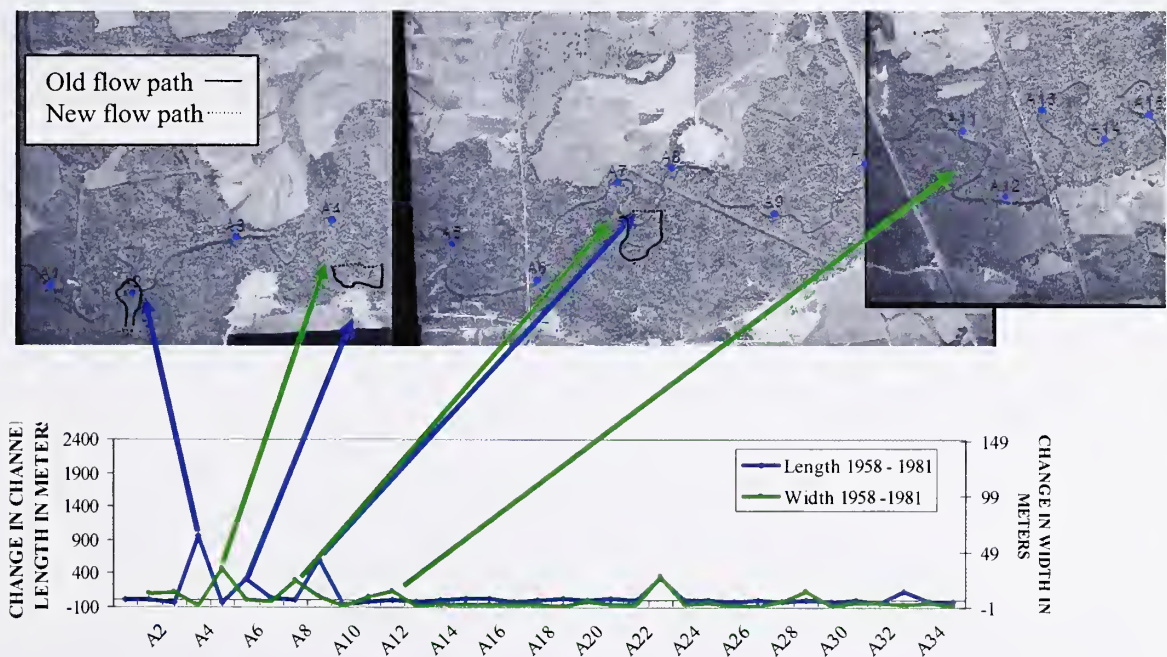
construction plans for the Tennessee-Tombigbee Waterway in the vicinity of the mouth of the Buttahatchee River from the U.S. Army Corps of Engineers.

## 5.1 Changes in channel morphology since 1950's

### 5.1.1 Air Photo Analysis

Air photos were available from the years 1958, 1981, 1992 and 1999. Each set of images was analyzed to obtain channel width at each RGA site, and channel length between each pair of sites. These lengths and widths were then compared between each set of air photos to obtain estimates of width and length changes in the channel. The differences between each set of air photos are discussed in detail in the following sub-sections.

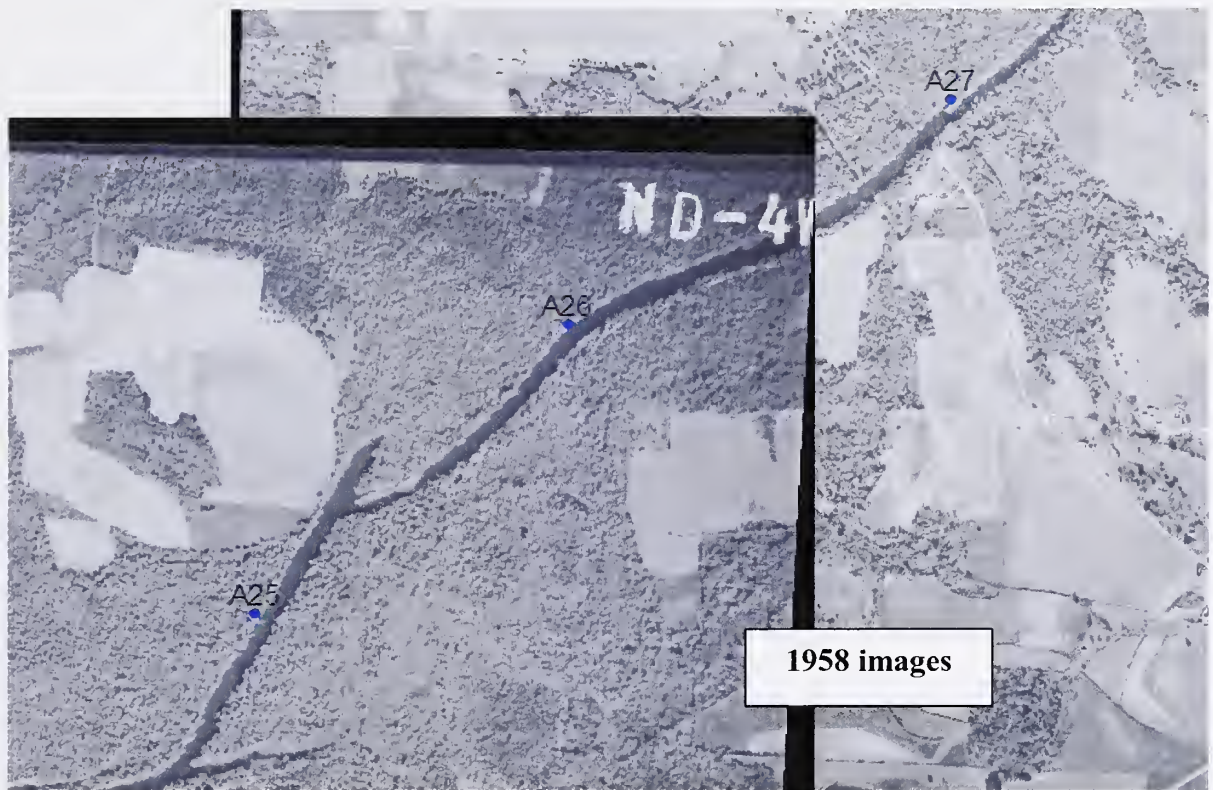
**Widening and length changes: 1958 to 1981:** Channel width and length changes in this time period were predominantly attributable to meander cutoffs occurring in Reach A. During this time period four cutoffs occurred in Reach A (between A2 and A3, A4 and A5, A7 and A8, and at A22; Figure 12), with an associated decrease in channel length totaling approximately 2.3 km (approximately 9 % of the channel length from the old river mouth to the upstream location of the cutoff at A22).



**Figure 12 – 1958 air photos with accompanying graph highlighting the locations of meander cutoffs and associated channel length width changes between 1958 and 1981 air photos.**



In addition, in the 1958 images, a section of reach A already appears to have been straightened (Figure 13).



**Figure 13 – Section of straightened channel (sites A24 to A27) in reach A in the 1958 images.**



A shortening of channel length will increase channel slope by decreasing the channel length between two points. The result of increasing channel slope is an increase in flow energy, and the river's ability to transport sediment, assuming no other changes in sediment supply. An increase in flow energy must then be dissipated in some way through changes in channel planform and geometry including incision and/or channel widening. In contrast a reduction in channel slope tends to lead to deposition and aggradation as less energy is available to transport sediment. Changes in width accompanied the meander cutoffs in the A reach, with widening generally occurring both upstream and downstream of the cutoffs. Maximum widening occurred 2-3 rkm's upstream of the cutoffs and approximately 1rkm downstream of the cutoffs (Figure 14)

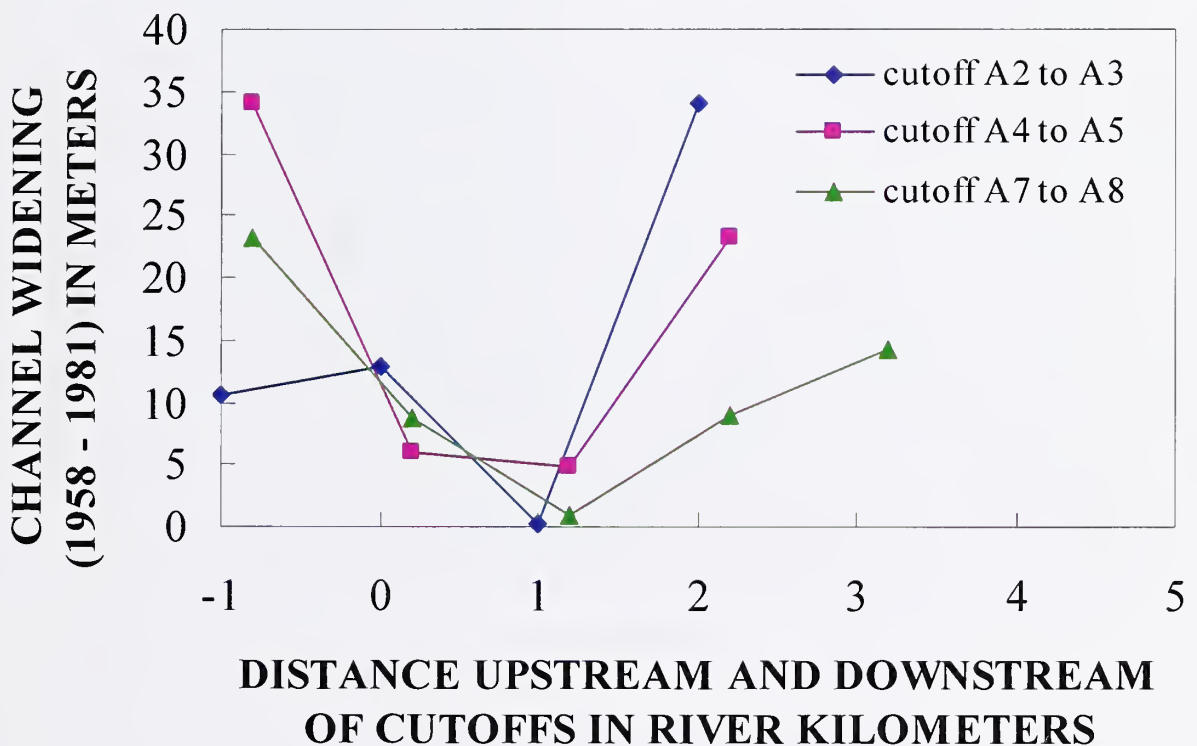
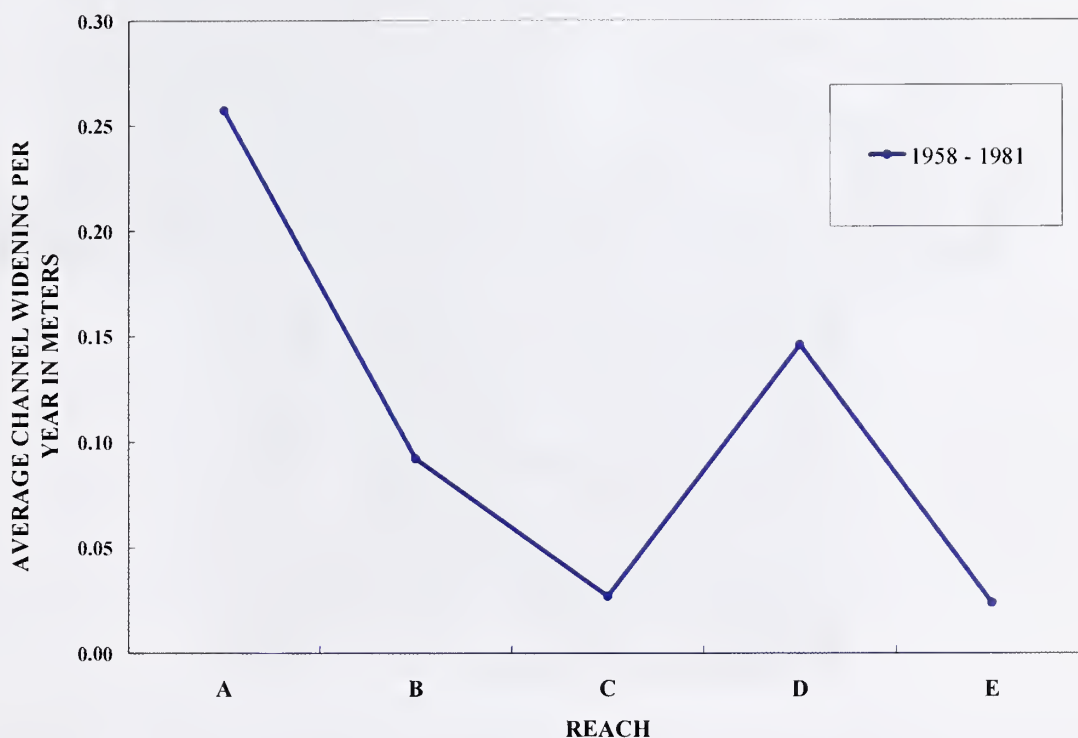


Figure 14 – Channel widening up- and downstream of the three cutoffs that occurred between the 1958 and 1981 air photos.



The average widening rate in reach A of the Buttahatchee River was higher than the other reaches during this time period ( $A = 0.23$  m/yr) as a response to the meander cutoffs seen in the air photographs. Lower average widening rates occurred throughout the rest of the river during this period ( $B = 0.09$  m/yr,  $C = 0.03$  m/yr,  $D = 0.15$  m/yr,  $E = 0.02$  m/yr), although small peaks on Figures 23 and 24 do show localized erosion at some sites. The widening rates show a general attenuation in channel response moving away from reach A, where most of the disturbances to the channel have been concentrated. The exception to this trend is the rate of widening seen in reach D (Figure 15).



**Figure 15 - Average widening rates for each reach taken from 1958-1981 air photos.**

Noticeable changes in channel width during this time period occurred at sites D108 and D114. Widening still occurred throughout the rest of the D reach, but at lower rates. Rapid widening is particularly evident at D108. Two of the possible explanations for the rapid widening seen at this site are discussed below. First, at site D108, a large gully can be seen to form in the field to the north of the channel at some point during the period 1958 to 1981. This gully may have delivered a great deal of sediment to the channel, thus reducing the capacity of the channel, causing channel widening to occur (Figure 16). Second, such rapid widening could have been caused by the presence of a debris jam, which would have deflected flow towards the margins of the channel, thus causing accelerated erosion at this site. No sign of a debris jam is visible on the air photos, but a



large jam does currently exist 10 km downstream at site D98. At site D114 the only noticeable change in the 1958 and 1981 images is that more land had been cleared for cultivation by 1981. In areas where cultivation occurs close to the channel, and riparian buffers are minimal, bank stability could have been adversely affected.

1957

No gullies in fields, and no extensive channel widening.

D108

1981

Note gullies and soil erosion on 1981 image compared to 1958 image, and accelerated erosion at this site

D108

1999

Note gully is no longer there. Bar in channel seems more stable (vegetation growing on it), and channel widening has decreased.

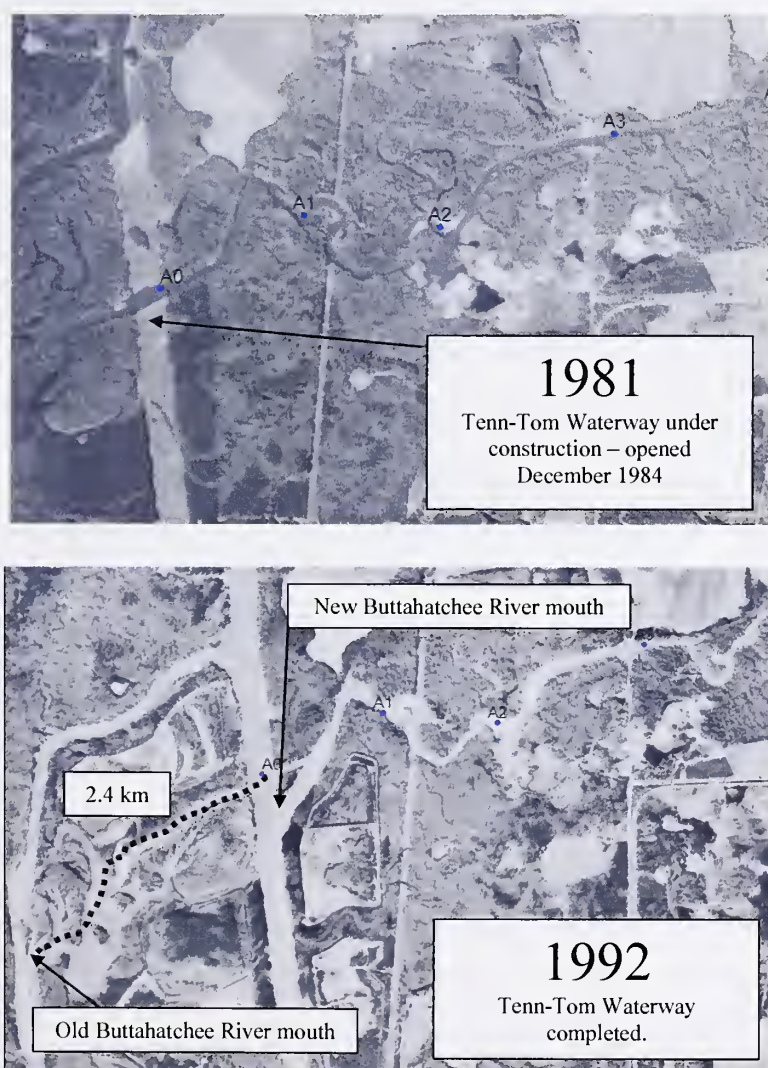
D108

**Figure 16 – Channel changes over time at site D108. Note the gully that forms in the 1981 image, and associated sedimentation and widening in the channel.**



**Widening and length changes: 1981-1992:** Channel width and length changes during this period were again concentrated at the lower end of the channel. Two main disturbances occurred between 1981 and 1992:

1. In the 1981 image, the construction of the Tennessee-Tombigbee Waterway (TTW) can be seen to be underway; the waterway opened in December 1984. Construction of the waterway relocated the mouth of the Buttahatchee River, cutting off 2.4 km from the lower end of the Buttahatchee River (Figure 17). The normal pool elevation in the Columbus pool is 163 f.a.s.l, and this level effectively raised the base level of the Buttahatchee River. The impoundment of the Columbus pool affects the Buttahatchee River up to about 1km upstream of its mouth (Jones, 1991). The raising of a channel's base level has the effect of causing aggradation in the lower reaches, by reducing water surface slope, flow velocities, and the energy available to transport sediment. Bank widening can also be associated with aggradation.



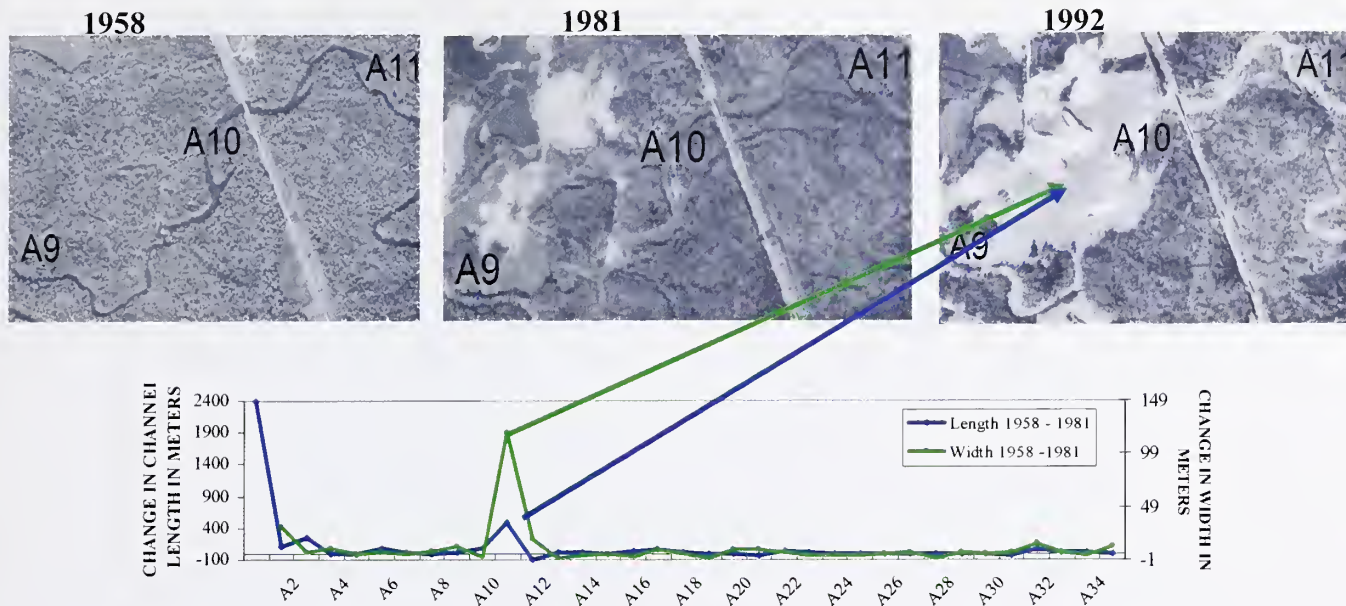
**Figure 17 – Air photos showing location of the mouth of the Buttahatchee River pre- and post-Tennessee-Tombigbee Waterway construction.**



In addition, the 1974 USACE design memorandum for the Columbus Pool suggested that local water tables could increase as a result of impoundment as normal pool elevation was higher than flow conditions under the “natural” river state. At the mouth of the Buttahatchee River this could have led to more frequent saturation of streambanks, thus increasing bank instability by the loss of shear strength during recessional stages.

2. Floodplain gravel-mining operations in reach A of the Buttahatchee River intensified in the late 1970’s and early 1980’s, with a series of gravel mines being situated just to the south of the HWY45 bridge near site A10. The geology and topography of the floodplains of the east-bank tributaries to the TTW (which includes the Buttahatchee River), contribute to the ability of the east-bank tributaries to supply significant bed material load to the TTW. Conversely the west-bank tributaries to the TTW tend to supply more of the suspended sediment load as they flow through finer grained materials. Simons *et al* (1982) encouraged gravel extraction in tributary source areas because their sediment transport analysis showed that the permanent rise in water surface at low and intermediate stages in the Columbus Pool, and subsequent increase in the Buttahatchee River base level would cause aggradation in the floodplain reaches of the Buttahatchee River throughout much of the year, thereby reducing the quantity of sediment delivered to the pool. Gravel mining in the tributary source areas would thus improve the hydraulic efficiency of the tributary reach (in this case the Buttahatchee River), and reduce problems associated with aggradation in the floodplain reaches of the tributaries, while also enhancing the delivery of coarse materials to the main stem of the TTW (Simons *et al*, 1982). The Simons *et al* report (1982) does warn however that over-exploitation of the tributary reaches could produce instability and bankline failure. Air-photo analysis shows that the river channel throughout the heavily mined section has captured abandoned and active gravel mines. In addition, during the winter floods of 1989, a berm separating the river from an active gravel mine just west of HWY45 was breached and a large quantity of loose gravel was transported downstream (Jones, 1991). The resulting capture of the gravel mines has significantly altered the channel’s course through this section (Figure 18).





**Figure 18 – Air photo images from 1958, 1981 and 1992, showing the gravel mine capture and resulting capture and shortening of the course of the river at this location.**

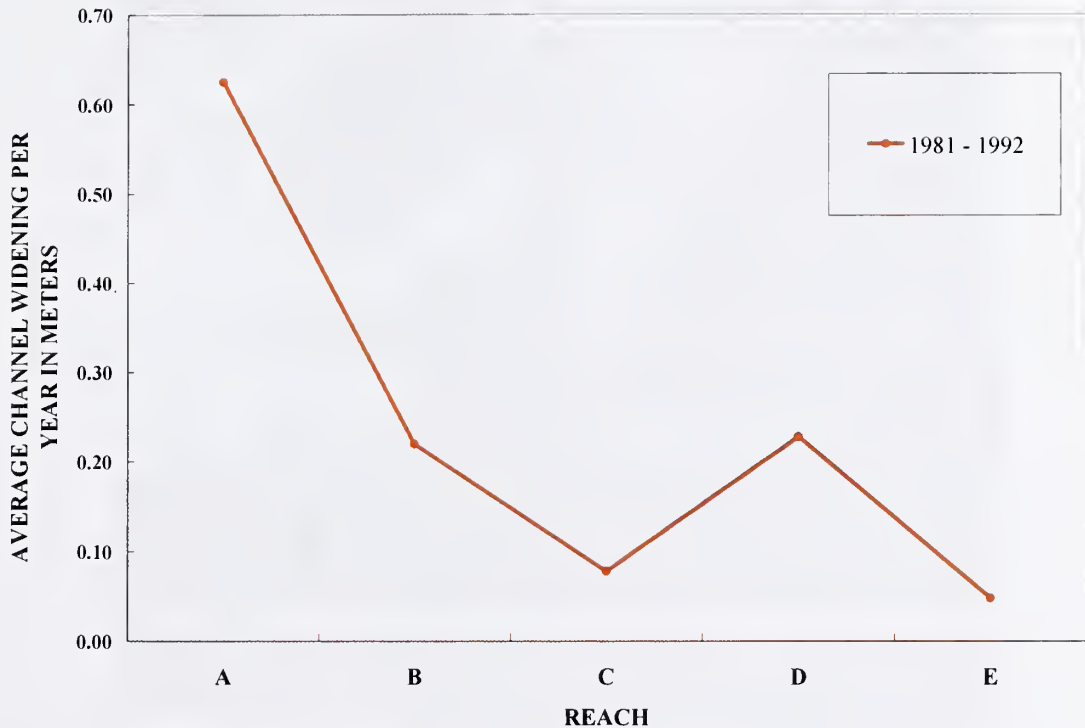
The mine capture that has occurred in the vicinity of site A10, may have caused the water surface elevation at this point in the channel to be lowered as the water is spread over a wider area. A reduction in water surface elevation would have an upstream impact as the river attempts to reduce the extra energy provided by the steepened flow gradient. This additional flow energy would tend to be dissipated by channel incision, channel widening, and/or lengthening, if sediment supplied from upstream remained the same after the disturbance. Land use issues in the upper part of the watershed have, however, affected sediment supply over the period of study, and the effects of this combined with the response of the channel to increased water surface elevation are discussed in more detail in the gage analysis section (5.1.2).

General widening occurred through the whole of reaches A and B and into the lower section of Reach C between 1981 and 1992. There was also a decrease in channel length due to TTW construction, and gravel mine capture. Cumulative shortening for whole length of channel studied equaled approximately 4 km during this time period, the vast majority of which occurred in reach A (Figure 26).

Average widening was 0.63 m/yr for reach A, 0.22 m/yr for reach B and 0.08 m/yr for reach C from 1981 – 1992 (Figure 19), compared to average widening rates of 0.23, 0.09 and 0.03 m/yr respectively for the 1958-1981 time period (Figure 15). Average widening rates can be seen to decrease from reach A to reach C; the disturbances to the river in the A reach, caused by TTW construction and gravel mine capture and ponding has had the greatest effect during this time period at sites in the vicinity of the disturbances. However, erosion during this time period was observed as far upstream as reach C, in



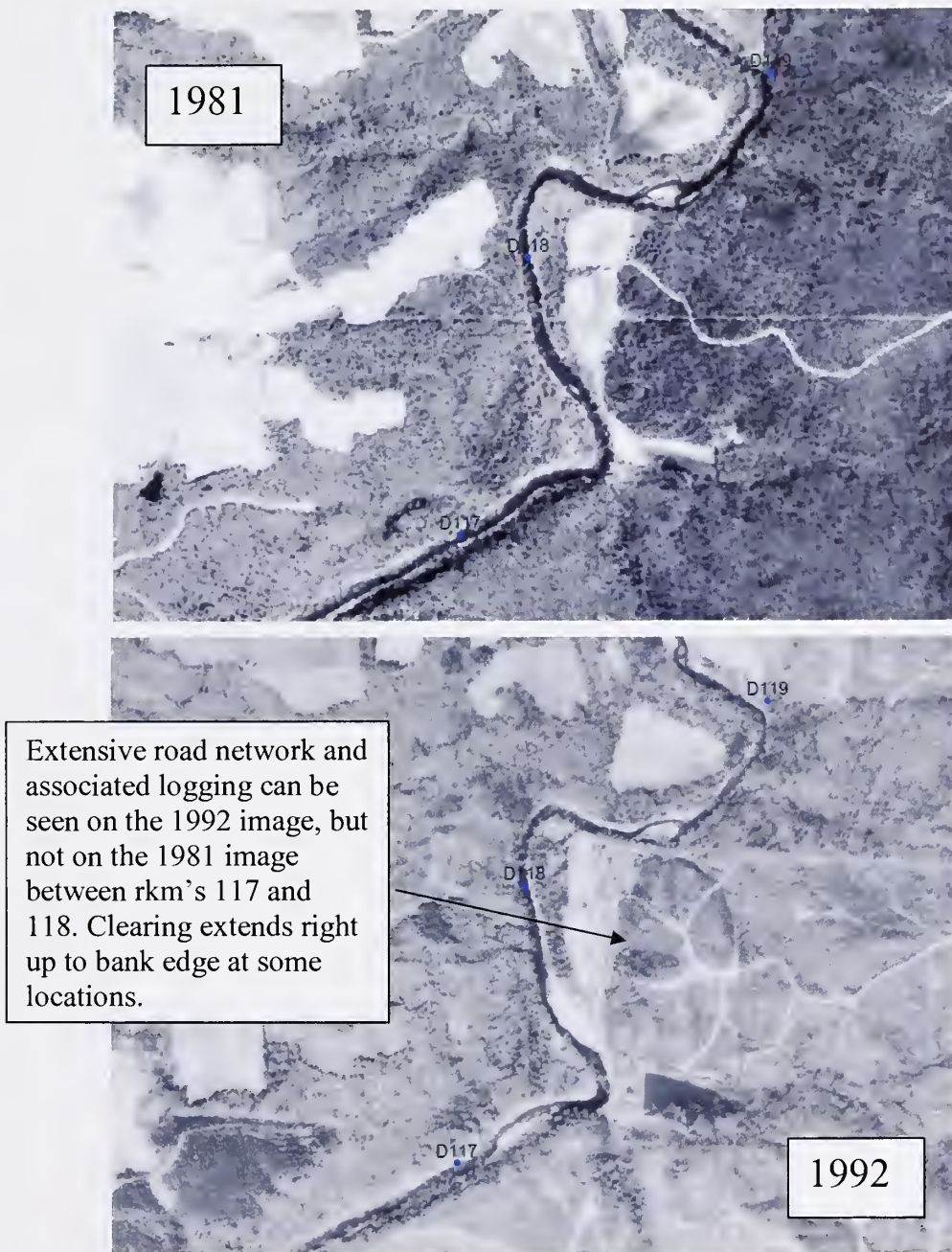
response to both anthropogenic disturbances during this time period, and the meander cutoffs that occurred during the previous time period.



**Figure 19 - Average widening rates in each reach taken from 1981 - 1992 air photos.**

The average widening rate in reach D was at its highest during the period 1981-1992 (Figures 19 and 27). Analysis of the air photography shows that sometime between the 1981 and 1992 images, a large area of land was logged on the east bank of the river between rkm's 117 and 118. The area of logging extended right up to the bank edge, and was accompanied by a grade control structure and check dam. Other areas of land clearance are also visible in this reach on the aerial photography (Figure 20).





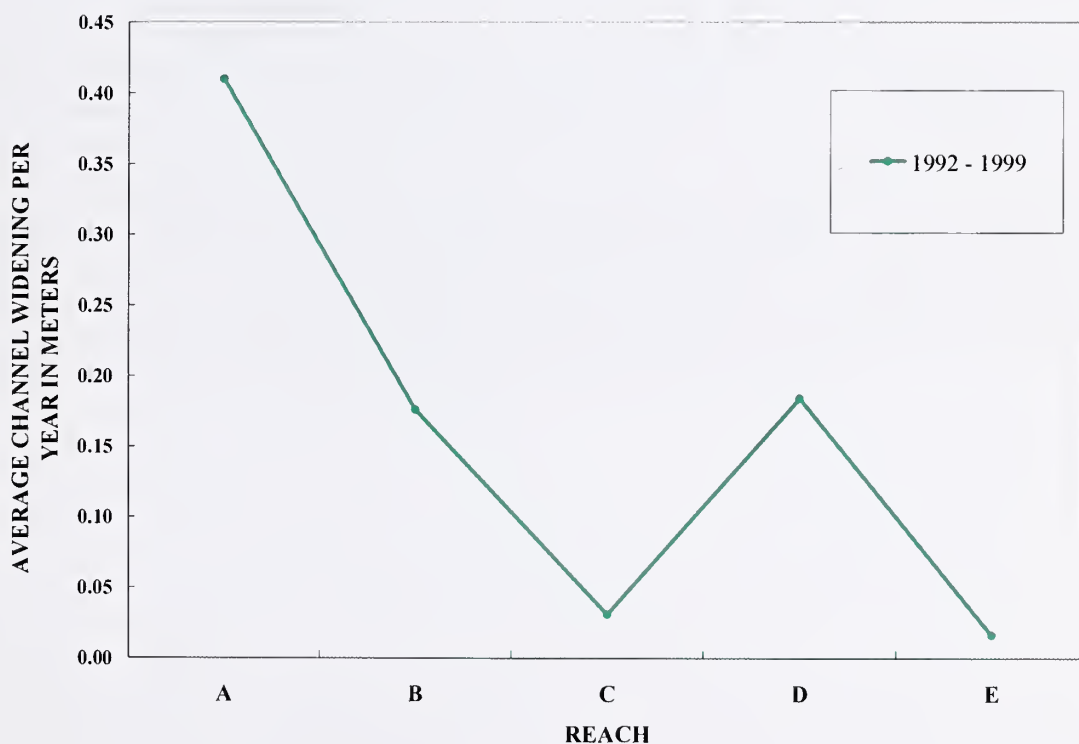
**Figure 20 - Air photography from 1981 and 1992 for rkm's 117 to 118, showing logging and land clearance on east bank of the Buttahatchee River.**



The land clearance that is evident from the air photographs would have increased the amount of sediment delivered to this reach of the Buttahatchee River through runoff. Indeed, air photography from 1992 shows that the D reach had a great deal of sediment deposition, with large bars accreting both vertically and laterally. The effect of this sediment deposition in the D reach was to create a positive feedback loop in which bar growth on the inner meander bends deflected the flow of the river towards the outer bends of the meanders, thus leading to bank erosion on the outer meander bends. Bank erosion then delivered more sediment to the channel which caused the bars to grow further, enhancing the process and the widening of the meander belt in this reach. The parts of the D reach that appear to be particularly unstable during this time period are rkm's 105 to 112 and 117 to 121. The rkm's between 112 and 117 occur in a relatively straight section of channel that passes through an area of topography quite different to the flat agricultural floodplain areas upstream and downstream of it. This 5 km stretch of the channel is bounded by an area of steep topography, with the channel remaining confined in a valley. This part of the river appears to be a transport reach, but widespread deposition occurred in the rkm's both up- and down-stream of this section.



**Widening and length changes: 1992 – 1999:** Analysis of air photos for the period 1992 to 1999 showed the lowest average annual rates of bank widening for any of the time periods studied. Bank widening rates were lower for all reaches during these years, averaging 0.41 m/yr for reach A, 0.18 m/yr for reach B, 0.03 m/yr for reach C, 0.18 m/yr for reach D and 0.02 m/yr for reach E (Figure 21). The highest rate of widening was still in reach A, and the 1992-1999 graph in Figure 24 shows that most of the changes in width during this period were concentrated in reach A, and the lower 10 km of reach B. Significant instability still seems apparent in reach A during this time period. Rates of widening in reach D were still noticeably higher than the upstream and downstream reaches during this time period, as the positive feedback between sediment deposition and bank erosion continued through this period of analysis. Changes in total channel length between 1992 and 1999 actually showed a slight trend towards increased channel length (Figure 26). This increased length was likely to be a result of the aggrading bars and extending meander bends occurring not only in reach D, but also in parts of the lower reaches. In the lower reaches the energy imbalance between sediment input and the energy available to transport sediment was also evident from bar accretion and bank instability seen in the air photographs.



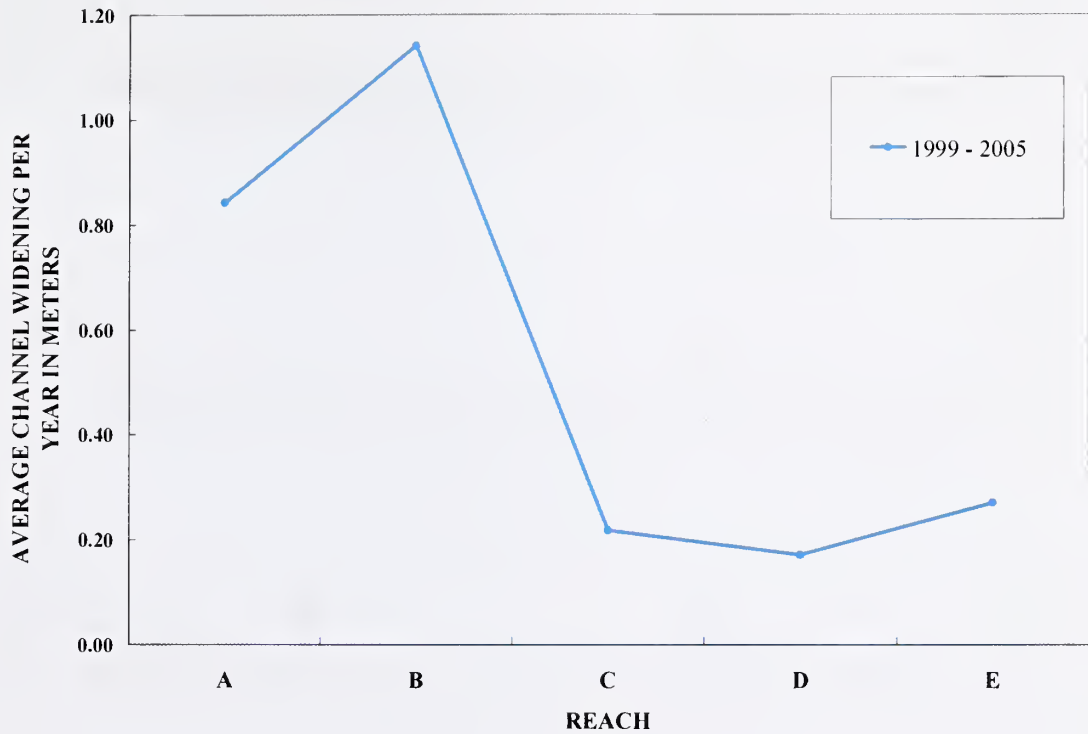
**Figure 21 - Average widening rates for each reach taken from 1992 - 1999 air photos.**



**Widening and length changes: 1999 – 2005:** The changes in width calculated for this time period show an increase in erosion in all reaches when compared with the 1992-1999 period. However, comparison of widening rates between this and previous time period is problematic as different techniques were used to obtain 1999 and 2005 bank-top widths: 1999 values were attained from air photo analysis and 2005 widths were measured in the field using a rangefinder. Each method has its own degree of error associated with it. For the air photo analysis, channel width was hard to obtain for some sites because of issues with image resolution and quality, and the presence of vegetation which can obscure the bank edges. These problems existed for all 4 sets of images, and care has therefore been taken in previous sections to discuss changes in widths in broad scale terms, rather than as absolute values. The measurement of channel width in the field can also be difficult. As well as the associated error with the measurements from the rangefinder itself, it is possible to have a degree of operator error when selecting an object to measure distance to. It was not possible to calculate channel length changes for this period as the most recent air photos available were from 1999.

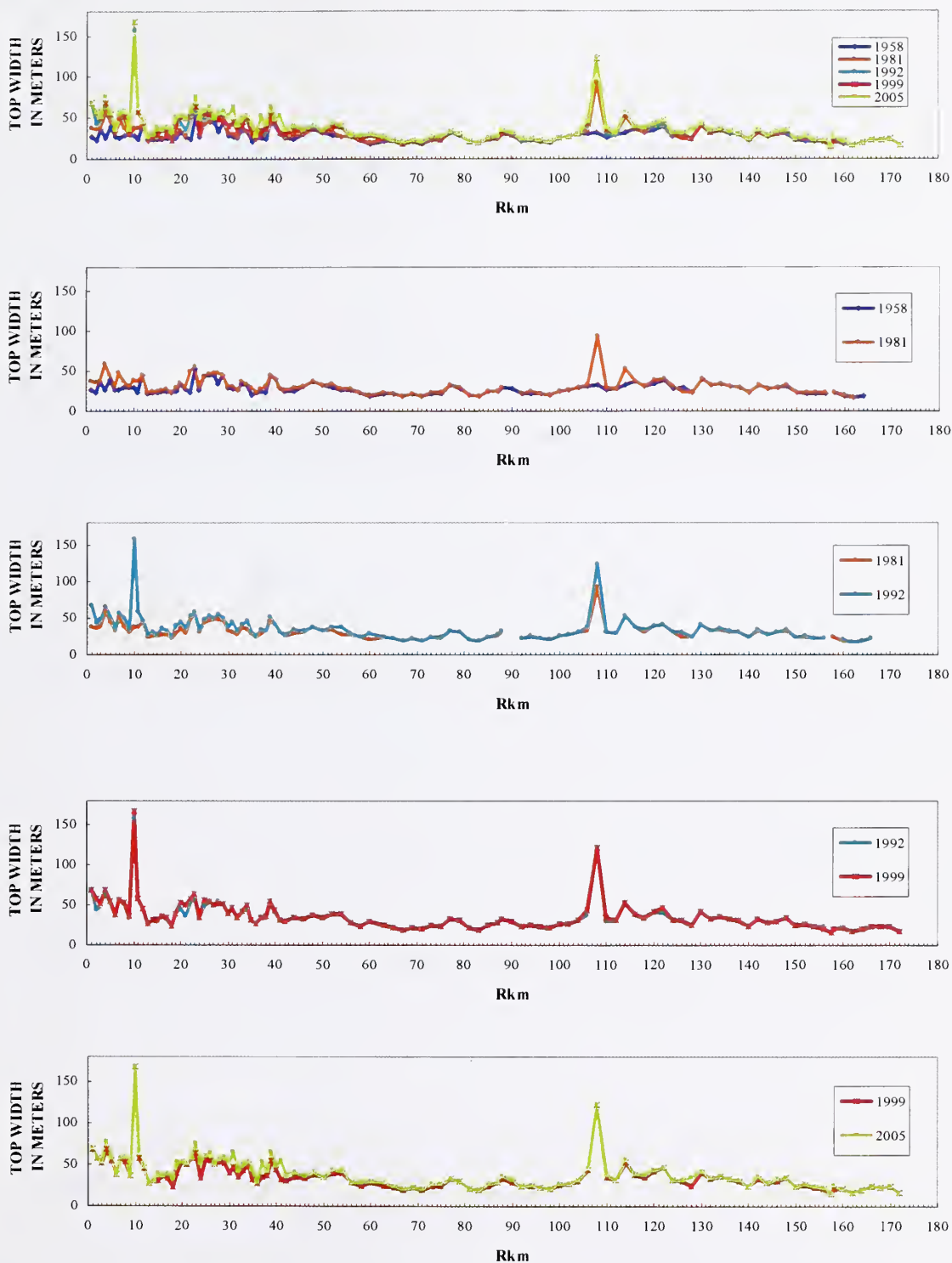
Average channel widening rates were 0.87 m/yr for reach A, 1.14 m/yr for reach B, 0.22 m/yr for reach C, 0.17 m/yr for reach D, and 0.27 m/yr for reach E (Figure 22). As stated above, calculation of the widening rates and amounts in this time period may have been affected by the differing methods for attaining widths. However, bearing in mind the high degree of instability noted both during the RGA's conducted from a boat in the river channel, and aerial reconnaissance from the helicopter flight, it does seem to be the case that the channel is currently unstable along large portions of the 172 km studied. The upper part of reach A and lower part of reach B seem to be the most unstable in this period of analysis (Figure 22). It is also interesting to note from Figure 22 that more widening is taking place in reach B in this time period than in reach A. It is possible that channel instability is moving upstream over time as the channel's response to the gravel mine capture (A10) in the late 1980's slowly migrates upstream. In addition, the average rate of widening in reach D seems to be lower in this last time period, with rates of widening however increasing in the reaches upstream of the D reach.





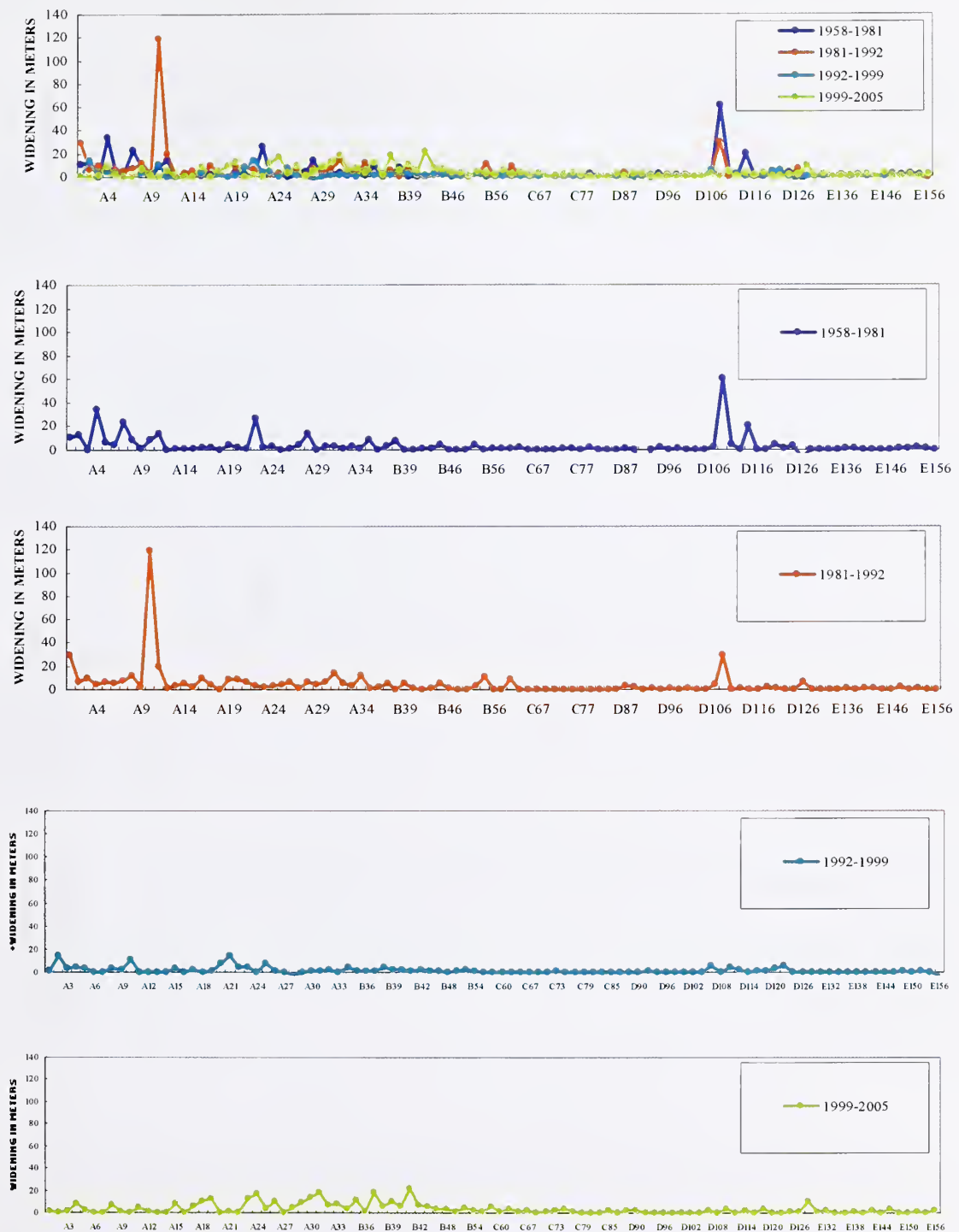
**Figure 22 - Average widening rates for each reach taken from 1999 air photos and 2005 field data.**





**Figure 23 – Channel top-widths measured from air photos (1958 – 1999) and in the field (2005).**





**Figure 24 – Changes in channel top-widths measured from air photos (1958 – 1999) and in the field (2005).**



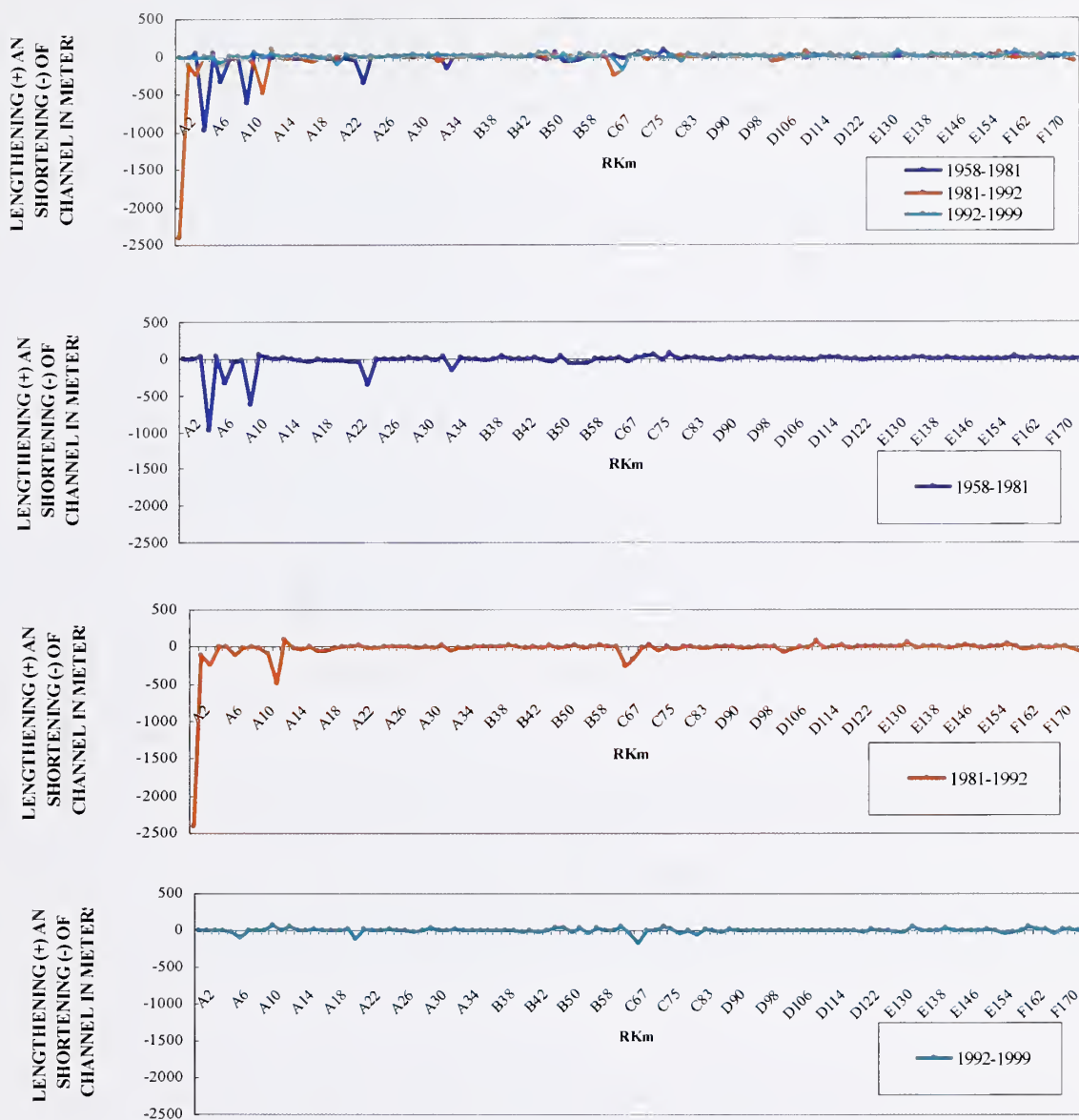
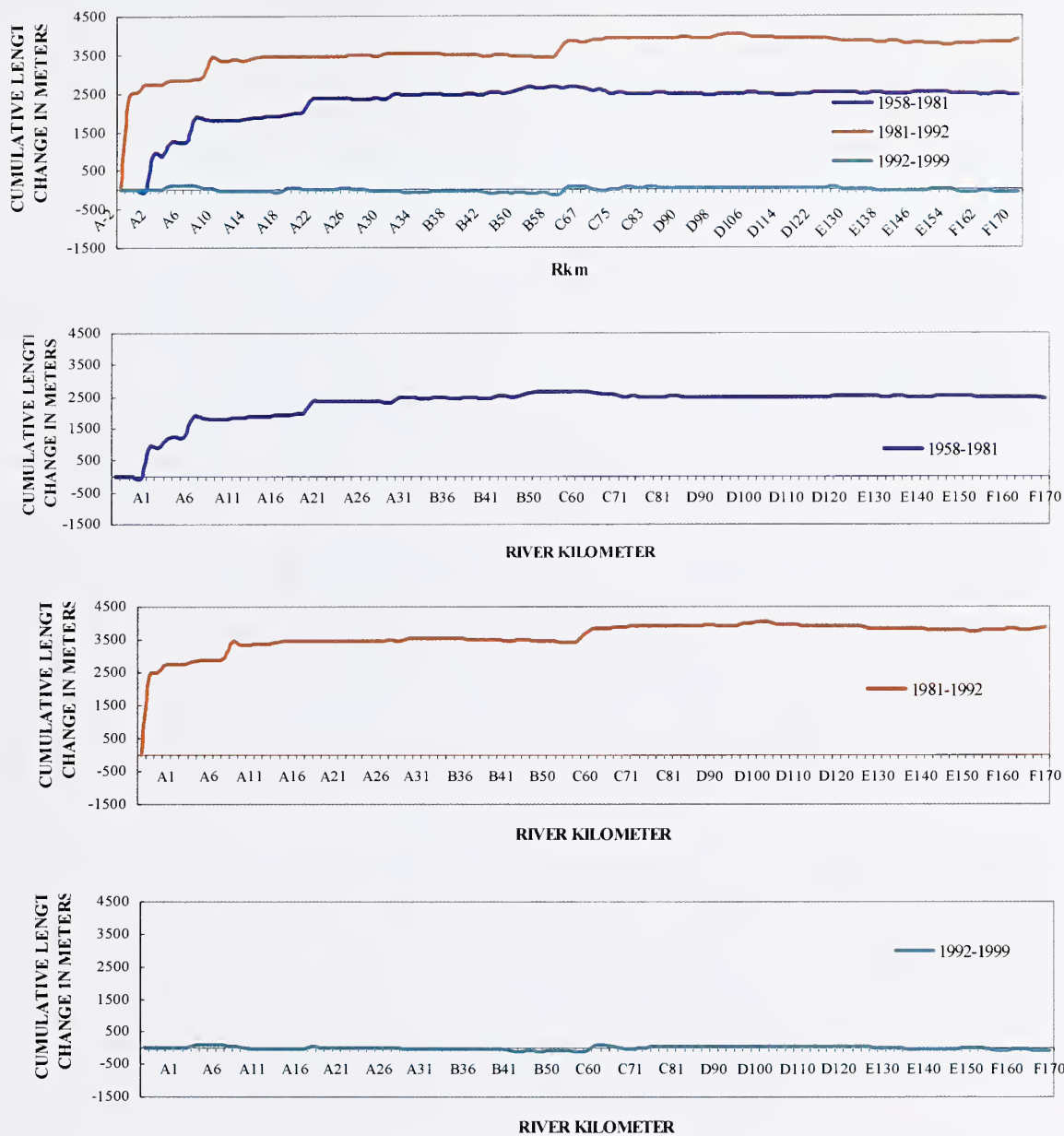


Figure 25 – Changes in channel length measured from air photos (1958 – 1999).





**Figure 26 – Cumulative changes in channel length (shortening) measured from air photos (1958 – 1999).**



### Summary of overall timing and patterns of erosion from 1958 to 2005

Figures 23 and 24 are useful in helping to understand the timing and relative locations of responses to disturbance on the Buttahatchee River between 1958 and 2005. From 1958 to 1981 widening occurred in response to meander cutoffs (reach A) while localized erosion and instability occurred in reach D. Erosion was therefore occurring in this time period, but erosion rates were not accelerated. Response to meander cutoffs may take decades, so the effect of the cutoffs was most likely continuing into the later periods of analysis.

In the 1981-1992 time period, in addition to channel responses to meander cutoffs from the previous time period, the channel began to respond to the raising of the Buttahatchee River's base level, shortening of the river at the mouth (by 2.4 km, 1984), and the capture and ponding of the gravel mines (at site A10). At the new mouth of the Buttahatchee River, the river is affected by the impoundment of the Columbus Pool on the Tennessee-Tombigbee Waterway; higher water levels at the mouth led to more frequent bank saturation, followed by drawdown, and associated bank instability when water was released from the Columbus Pool. The rise in base level of the Buttahatchee River has caused the river to be aggradational for much of the year in the lower reaches. Aggradation at lower end of the Buttahatchee River has, therefore, occurred. Evidence for this can be seen as sand bars deposited on armored gravel beds. Repeated meander cutoffs and associated steepening of water-surface slope historically supplied the Buttahatchee River with enough energy to create armored gravel beds. Armored beds tend to accumulate in areas of natural scour in the river, such as on regions of the bed experiencing degradation, and on the upstream end of islands and bars. Coarser gravel fractions have a tendency through hydraulic sorting to armor the bed, thereby arresting excessive scour, and preventing excessive sediment movement from the bed.

The breaching of gravel mine berms led to extensive ponding and redirecting of the river at site A10, with a resulting increase in water surface slope thereby initiating another channel response upstream of this site. The responses of the Buttahatchee River to the TTW construction and gravel-mine capture in the time period 1981-1992 were thus superimposed onto the responses to the meander cutoffs that were already occurring, further complicating the response of the channel. As the beds in the lower reaches (A and B) are dominated by partially armored gravel beds, most of the channel response to instability caused by the disturbances has occurred through widening.

From 1981 to 1992, the erosion in the upper part of reach A and in reach B was possibly a response to the cutoff that occurred at A22 sometime between 1958 and 1981 (it is unlikely that the channel response from the gravel-mine capture could reach that far up the channel so quickly). In the 1992-1999 graph the upper part of reach A and reach B appear to be less unstable than in the previous time period. This reduction in instability indicates perhaps that the channel had finished adjusting to the meander cutoff at A22. The erosion in reach A between 1992 and 1999 occurred from A18 to A26 (Figure 23) and is slightly upstream of a section of high channel instability in the 1981-1992 graph (Figure 23), most likely a response to the gravel mine-ponding. The response to the



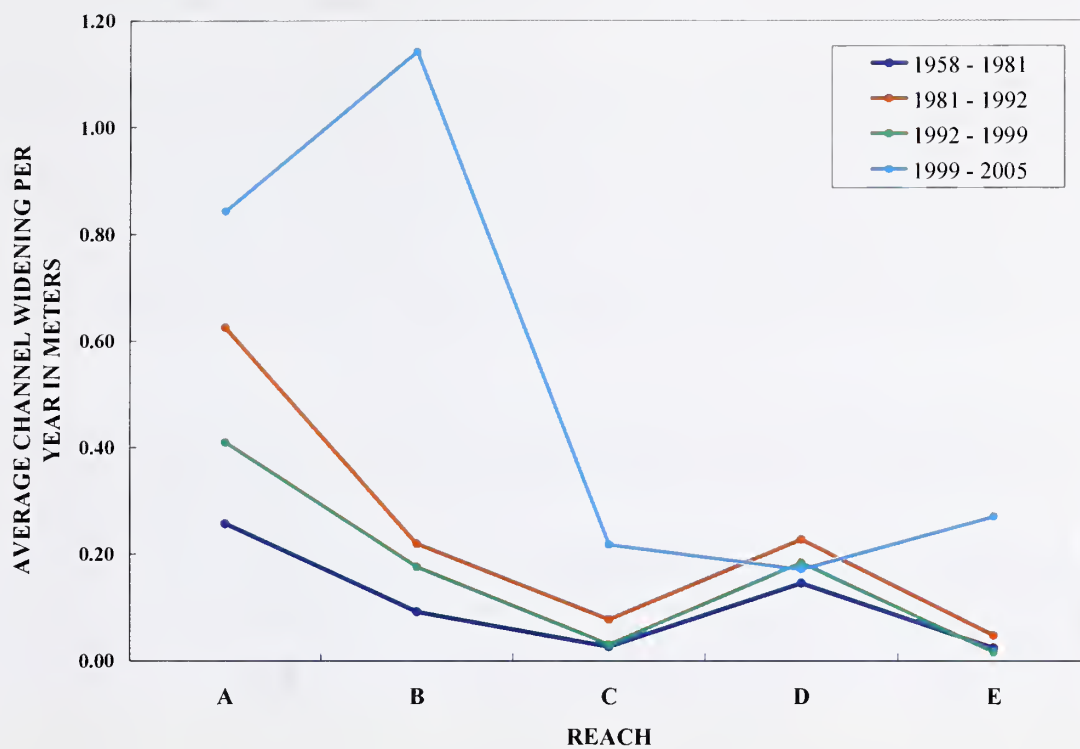
gravel-mine ponding, therefore appears to have migrated upstream between 1992 and 1999, and then migrates further upstream during the 1999-2005 period in which the upper part of each A, reach B and lower end of reach C became more unstable. Average widening rates for each reach, in each time period are summarized below in Table 7 and Figure 27:

**Table 7 – Average widening rates for each reach in each time period of analysis.**

	Average width change per year (m)			
	1958 - 1981	1981 - 1992	1992 - 1999	1999 - 2005
A	0.26	0.93	0.41	0.84
B	0.09	0.22	0.18	1.14
C	0.03	0.08	0.03	0.22
D	0.15	0.23	0.18	0.17
E	0.02	0.05	0.02	0.27

During the first three time periods of analysis it can be seen that there was a general attenuation in average widening rates moving upstream away from reach A, where most of the disturbances were concentrated. The exception to this trend is reach D, in which rapid rates of widening identified in the air photos are a result of channel migration related to excessive sediment emanating from logged areas and the close proximity of these activities and agricultural land-use to the river at some locations. This point is discussed in further detail in a later section on land-use (Section 5.2.5). The other noticeable trend is that in the last time period (1999-2005), the peak average rate of bank widening occurs in reach B, which supports the idea that the effects of disturbances that occurred in reach A are now migrating upstream into the higher reaches. The channel widening rates and instability shown in this section therefore seem to suggest that the Buttahatchee River is responding to two different areas of disturbance: first modifications to the A reach from TTW construction, gravel mine capture and meander cutoffs, and second, a positive feedback loop that has developed in the D reach as a result of excessive sediment delivery to the channel, leading to bar accretion and associated bank erosion at outer meander banks. Sediment delivered to the channel in the upper reaches may also be having a significant impact on processes occurring downstream, so not only are there channel responses moving upstream from the disturbances in reach A, but land-use issues and bank failures in the upper reaches are also affecting sediment transport and related channel forms and processes in the reaches downstream of the sediment sources.





**Figure 27 – Average rates of widening for each reach in each time period excluding mine ponding from average rates of widening.**



### 5.1.2 Channel Changes at Gauging Stations

Mean daily discharge, and peak annual discharge data were analyzed for the time periods between the air photographs to see if flow trends have varied over the time periods. In addition, summary data from USGS discharge measurements were analyzed to interpret the magnitude and timing of changes in channel morphology. USGS gage data were available for a number of gages on the Buttahatchee River and its tributaries (Table 8). However, only two of these gages have periods of record extending over most of the period of air photo analysis. These two gages are 02439400 (Buttahatchee River at Aberdeen) and 02438000 (Buttahatchee River below Hamilton).

**Table 8 – Gage numbers and periods of record for the Buttahatchee River and its tributaries. Gages with records extending across the periods of air photo analysis are highlighted in yellow.**

State	Station number	Station location	Period of record
Alabama	02438700	Mill Creek near Detroit	1959 – 1967
Alabama	02438710	Spruiell Branch near Detroit	1980 – 1981
Alabama	02437900	Woods Creek near Hamilton	1959 – 1965
Alabama	02446500	Sipsey River near Elrod	1928 – 2005
Alabama	02438000	Buttahatchee River below Hamilton	1951 – 2004
Alabama	02438500	Buttahatchee River near Hamilton	1941 – 1950
Alabama	02439000	Buttahatchee River near Sulligent	1939 – 1959
Mississippi	02439400	Buttahatchee River near Aberdeen	1966 – 2004
Mississippi	02439500	Buttahatchee River near Caledonia	1942 – 1951

#### **02439400 (Aberdeen) Reach A: period of record 1966 to 2004.**

Changes over time in the water-surface elevations (WSE) for a selected discharge can be used to interpret changes in channel morphology over the time period. This is termed “specific-gage analysis”. A decrease in WSE over time represents either channel incision and/or channel widening. Conversely, an increase in WSE represents either aggradation on the bed and/or channel narrowing. Three discharges were selected, representing low, medium and high stages (3, 10, and 50 m<sup>3</sup>/s) in an effort to attribute changes in WSE to specific changes in channel geometry. Generally, the lowest discharge selected is used to infer changes on the channel bed.

Specific-gage analysis at the Aberdeen gage shows an increase in the WSE at the two lowest discharges, indicating a consistent trend of mild aggradation (between 0.4 and 0.5 cm/y) over the period of record (Figure 28). At the higher discharge (50 m<sup>3</sup>/s) which includes any changes in channel width, the trend is reversed with WSE decreasing slowly with time. The decrease in WSE at this flow level result indicates that the channel was widening with time, notwithstanding the deposition occurring on the bed. This trend is



more pronounced if viewed in more detail. Note that between 1966 and 1976, WSE at  $50\text{m}^3/\text{s}$  was increasing, indicating more rapid channel filling, but that this trend was reversed in 1977. Because the analysis at the lower flows shows consistent aggradation, this seems to indicate that channel widening may have been initiated about this time. It is difficult to determine the exact cause and effect of these trends, however, the large flood flows of 1973 must have delivered large quantities of sediment to the river that was then eroded in subsequent years. This interpretation is supported by depth-discharge and width-discharge relations generated from USGS discharge-measurement data (Figures 29 and 30). The mid-1970's changes in channel depth and width shown in Figure 30 for a given discharge can be seen to have taken place prior to TTW completion but is coincident with the start of construction in the mid-1970's.

The data show that average flow depth for a specific discharge increased by approximately 0.5 m at the Aberdeen gage during the 1970's. This initially seems contradictory to the aggradation results shown in Figure 28, but appears to be the net result of preferential deposition on an inside bend causing narrowing of the flow area for medium discharges and hence, an increase in average flow depths. These processes cause an increase in the river's ability to transport sediment by enhancing stream power and average boundary shear stress. At a discharge of  $50\text{m}^3/\text{s}$  the increase in slope provided by the channel cutoffs in combination with the increase in hydraulic depth resulted in a 52% increase in average boundary shear stress at this flow rate.

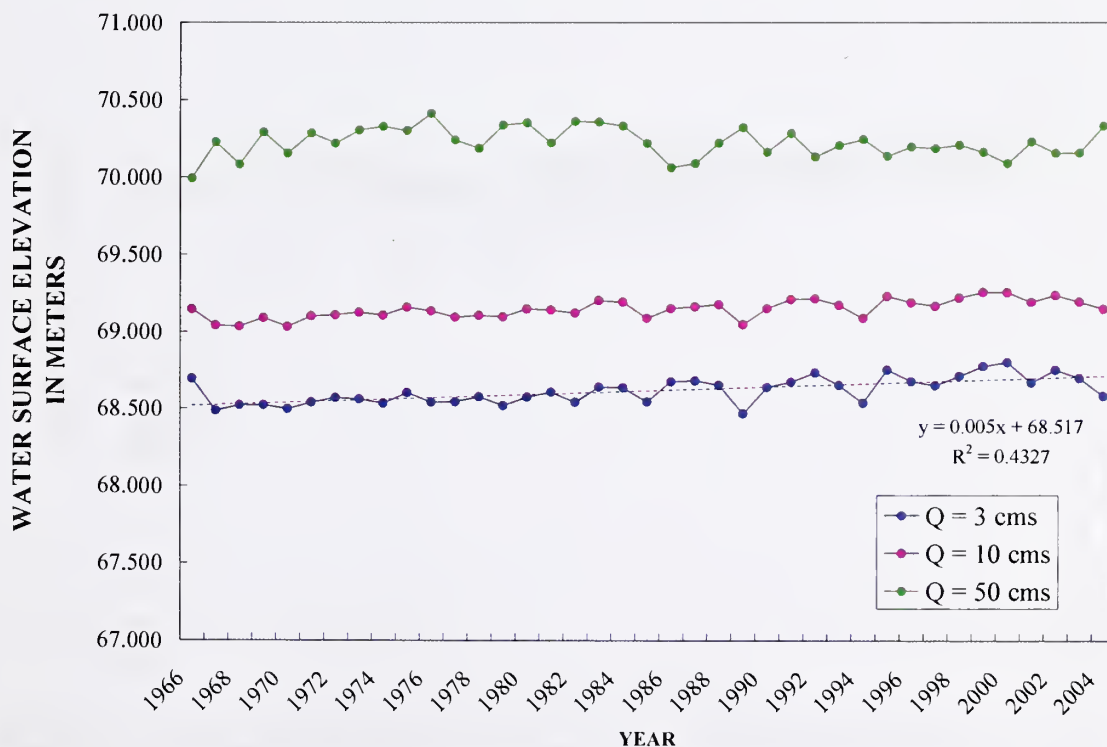
Further analysis of the data suggests a small amount of flow deepening occurred between 1975 and 1977, with a slight reversal in this trend until 1984 when the remainder occurred. The earlier deepening may have been in response to the meander cutoffs that occurred during this time period in reach A of the channel, or may have coincided with the start of construction on the Tenn-Tom Waterway, which began in the 1970's. The remaining increases in hydraulic depth (Figure 28;  $50\text{m}^3/\text{s}$ ) occurred from 1984 to 1985 when more "normal" flows returned following the dry years of 1978 to 1981 (Figure 30A). Although this renewed period of flow deepening coincided with the opening of the Tenn-Tom Waterway and the impoundment of the Columbus pool in December 1984 that actually caused aggradation in the lower-most reaches of the Buttahatchee River, the Aberdeen gage is a considerable distance upstream (rkm 42) and was probably not affected. Thus, this second period of increased hydraulic depths may have been related to the gravel-mine ponding at site A10 (occurred *sometime* between 1981 and 1992 images), a continued response to the meander cutoffs, and/or continued preferential deposition on inside bends.

A plot of width-discharge for the time period on record indicates some widening of the channel at the location of the gage, particularly from 1975 to 1976, with width being fairly stable since then. This increase in top width occurred during the same period as the increase in hydraulic depth at this site, supporting the previous discussion of top-bank widening during the mid 1970's. Alternatively, the bridge may have been replaced (or modified) at this time (this would explain why the channel has not widened directly at the gage since 1976, even though channel widening has occurred extensively throughout the rest of reaches A and B since the 1981-1992 time period).



Discharge data for the Aberdeen gage (02439400) shows the large flood flow of 1973, and also shows a series of drier years from 1978-1981 and from 1985 to 1989 (Figure 30A and 30B). Larger discharge events occurred in 1990 and 1991 following the drier years that preceded them. Dueitt (1999) suggested that the series of drier years in the late 1980's may have led to fluvial erosion of the lower banks, thus steepening the bank profiles, and decreasing their stability such that when larger flow events occurred in 1990 and 1991, mass-wasting was widespread. Tension cracks may also have formed during these drier years, producing potential locations for rapid infiltration and preferential flow, resulting in potential locations for failure planes. Mean daily discharges across the entire period of record show little variation between the time periods analyzed, except for the dry years in the late 1980's.

The causes of channel changes to the Buttahtatchee River in the vicinity of the Aberdeen gage (rkm 42) are complex and the result of multiple disturbances of varying magnitudes occurring at different times. Some of these, including the construction of the TTW, meander cutoffs, and capture of the gravel pits have been previously discussed. Others, such as the effects of upstream land use will be addressed in later sections. Still, mild aggradation at the Aberdeen gage between 1966 and 2004 suggests that the river is unable to transport all of the sediment delivered to it from upstream sources, be they upland areas and/or streambanks. The increase in hydraulic depth and the consequent increase in available shear stress during the mid 1970's and early 1980's indicates a response to these heightened sediment loads during this period.



**Figure 28 – Specific gage analysis for 02439400 Buttahatchee River at Aberdeen 1966-2004.**



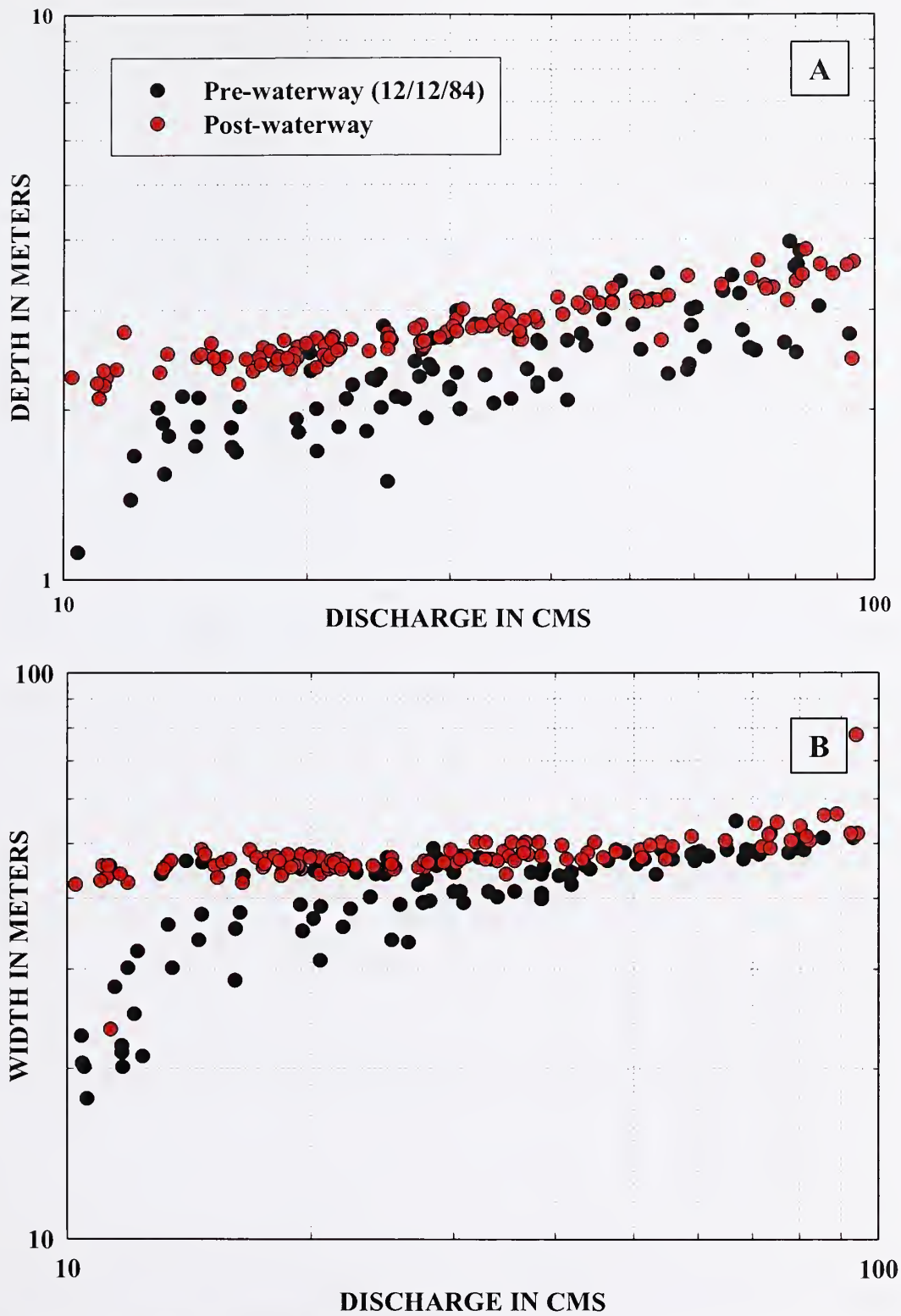


Figure 29 – A) Discharge-depth relation and B) discharge-width relation for gage 02439400 Buttahatchee River at Aberdeen, with data separated into pre- and post-Tenn-Tom Waterway completion.



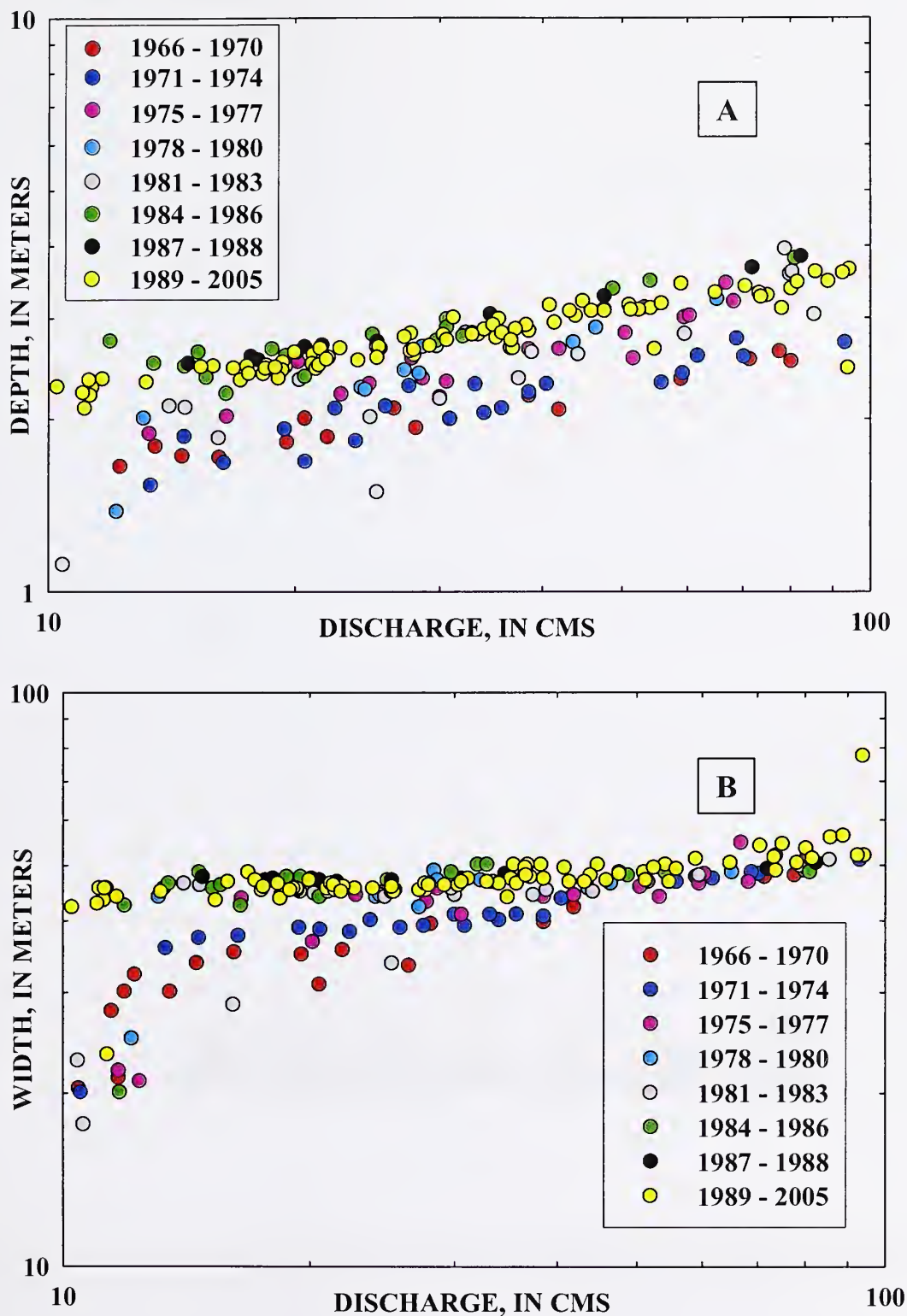
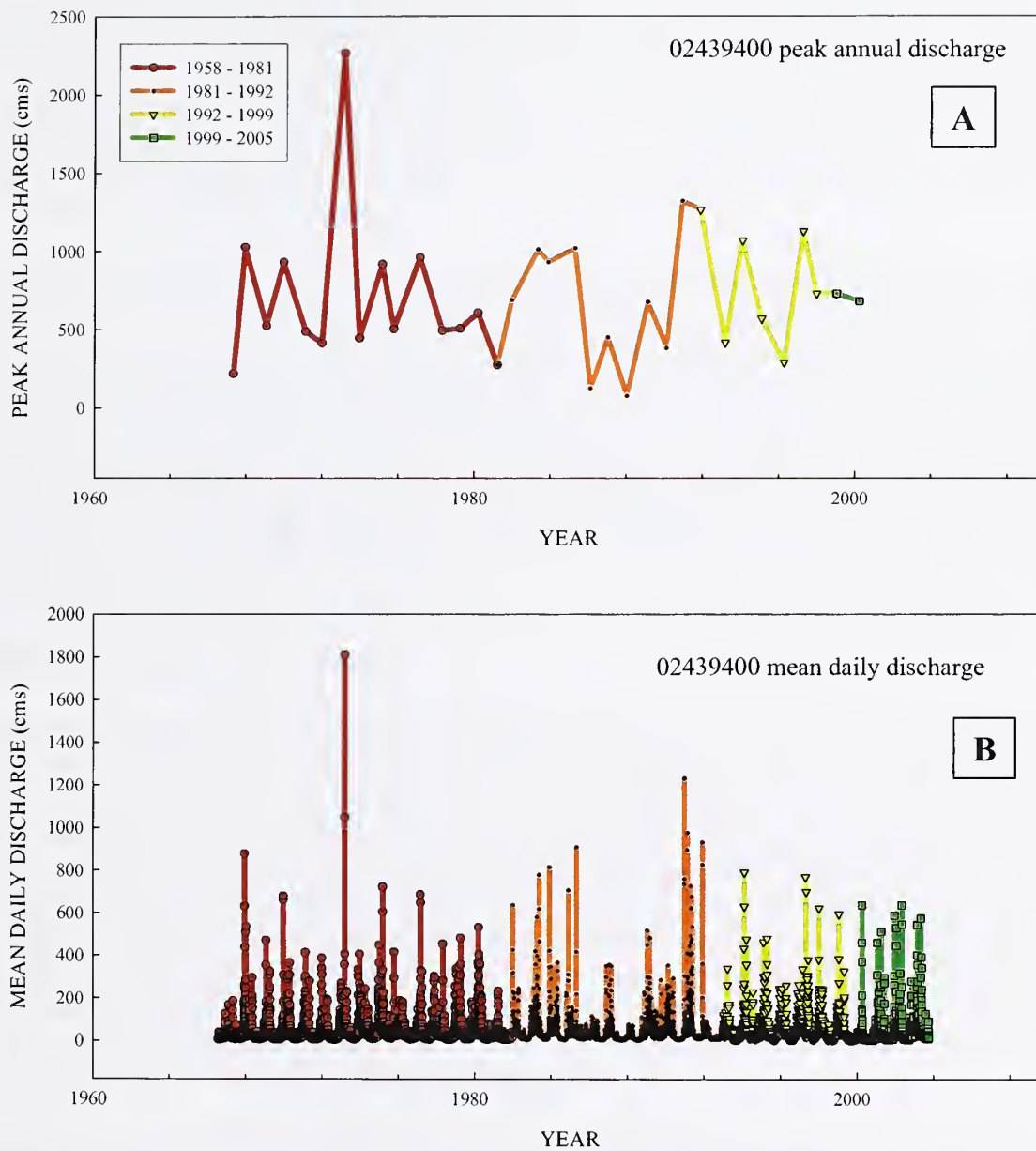


Figure 30 – A) Discharge-depth relation and B) discharge-width relation, for gage 02439400 (Buttahatchee River at Aberdeen), with data separated into different years to distinguish specific changes over time.





**Figure 31 – A) Peak annual discharge data and B) mean daily discharge data, both separated into the time periods between the air photos. Gage 02439400.**



### Excess Shear Stress Analysis at Gage 02439400, Buttahatchee River at Aberdeen

The  $D_{50}$  for the particle counts carried out 2 km upstream and 2 km downstream of the 02439400 gage vary from 15 to 22 mm. An analysis of excess shear stress shows that at  $\tau^*_c = 0.03$ , critical diameter size for particle entrainment at that gage is approximately 31 mm ( $\tau_e > 1$ ), whilst critical diameter size for bed movement is approximately 10 mm ( $T_e > 3$ ). Particle counts for river kilometers 40 to 44 showed that 32% of the bed material is finer than 32mm. 68 % is therefore coarser and can't be entrained even under the highest discharges recorded at this gage. 6% of the bed material is finer than 10 mm. Therefore 94 % of the material will not experience bed movement even under the highest Q conditions recorded at this gage.

Excess shear analysis in the sand particle range suggests that at  $\tau^*_c = 0.03$ , sand can be entrained 99.2 % of the time ( $\tau_e > 1$ ) and bed movement of sand particles can occur 73.9 % of the time. The shear stresses therefore show that sand can be entrained and transported under all but the lowest discharges at the 02439400 gage and help to explain the dominance of the gravel bed material in the thalweg at this location. However, bar accretion at the gage site does suggest that although the river has the energy to entrain sand at this location, there is too much sand entering the reach to all be transported. Further upstream the presence of more sand on the bed in addition to accreting bars suggests an even greater imbalance between available energy and the sediment being introduced to the system.

### 02446500 Gage on Sipsey River

Except for a period in the mid-1970's when the gage was not operational, the record from this station represents the longest in the basin starting in 1939 and extending to the present. Specific-gage analysis at 3 and 10 m<sup>3</sup>/s shows a relatively consistent trend of mild aggradation (0.7 to 0.8 cm/y) since 1955 (Figure 32). Before this time, it seems that the river was experiencing mild downcutting. It is possible that the data from 1939-1954 are indicative of the attenuation of a downcutting phase that may signal a more intense period of incision and widening prior to installation of the gage. Although merely speculation, this period of incision may be the result of improved soil conservation measures and reduced sediment loads from upstream sources. These types of measures and consequent channel changes were common throughout the region and other areas of the Midwestern United States during this period.

Trends of channel depth and width at specific discharges are generally supportive of the interpretations from the specific-gage analysis. Channel width is shown to increase over the period with the rate of increase slowing for the latest periods (Figure 33B). This would be typical of streams that had undergone downcutting, resulting in widening and then aggradation of the bed during stage V. The reduction in widening rates occurred as aggradation became the dominant trend. Field observations taken along the lower end of the Sipsey River suggest that the sites studied are currently stable (stability indices less than 10), but that the channel appeared to have undergone a period of mass failures sometime in the past. Anecdotal evidence from local residents suggests that the Sipsey



River was a stable, gravel bed stream, until sometime in the past, bank widening occurred, the channel became more unstable, and the gravel bed filled with finer sediments.

Sediment delivered to the Buttahatchee River at about rkm 60 from the Sipsey River has, therefore, probably decreased over the past 50 years. It is also important to note that there is no evidence of a disturbance migrating up the Sipsey River from the Buttahtachee River and that aggradational trends are similar (although greater) than at the Aberdeen gage over the period.

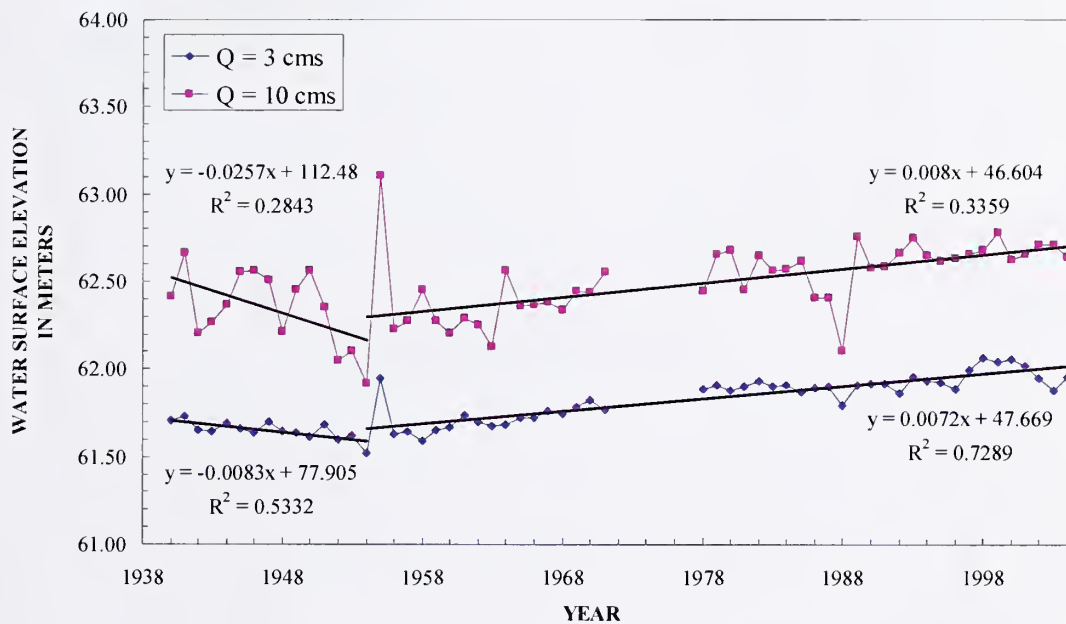


Figure 32 – Specific gage analysis for gage 02446500, Sipsey River near Elrod.



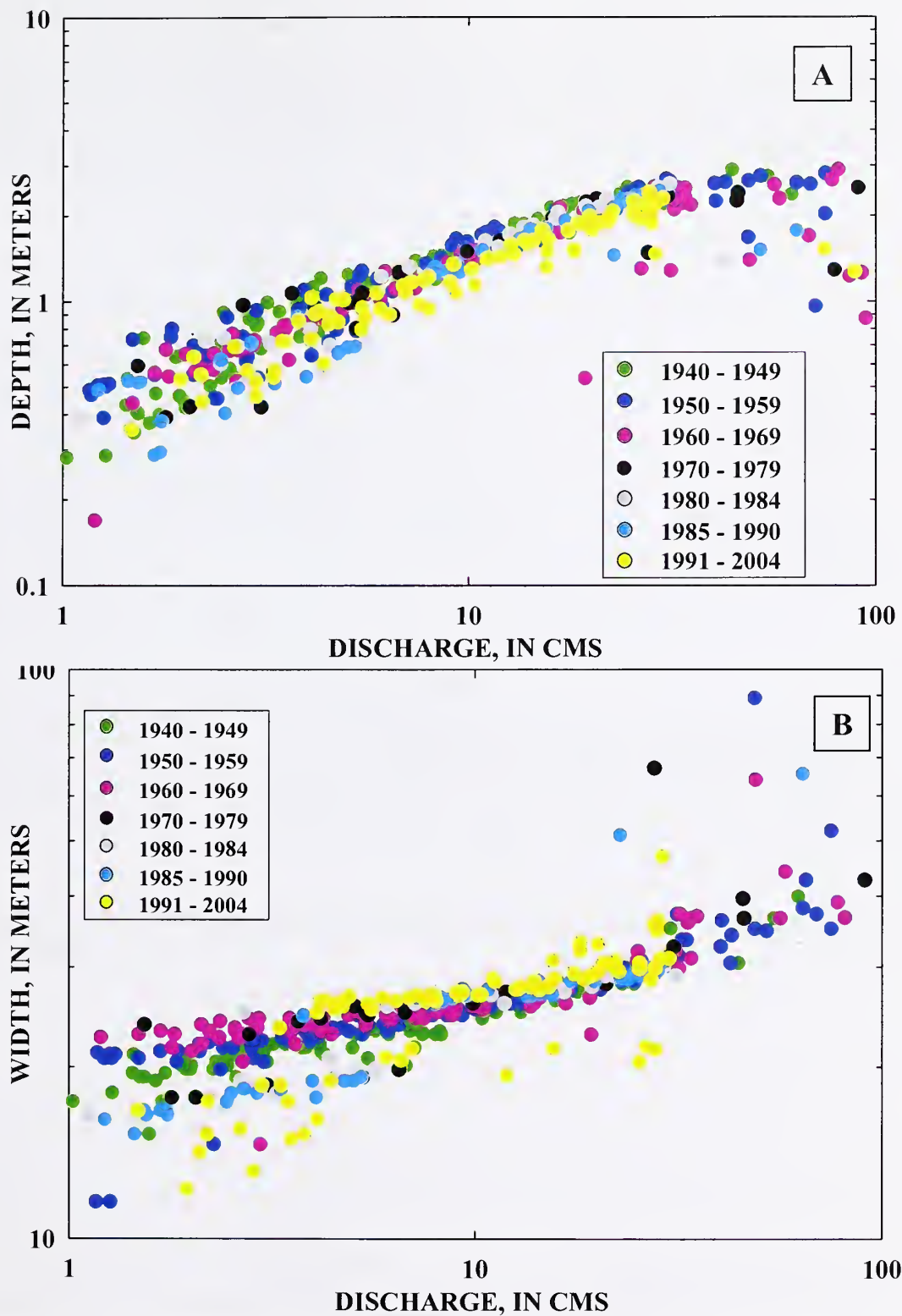
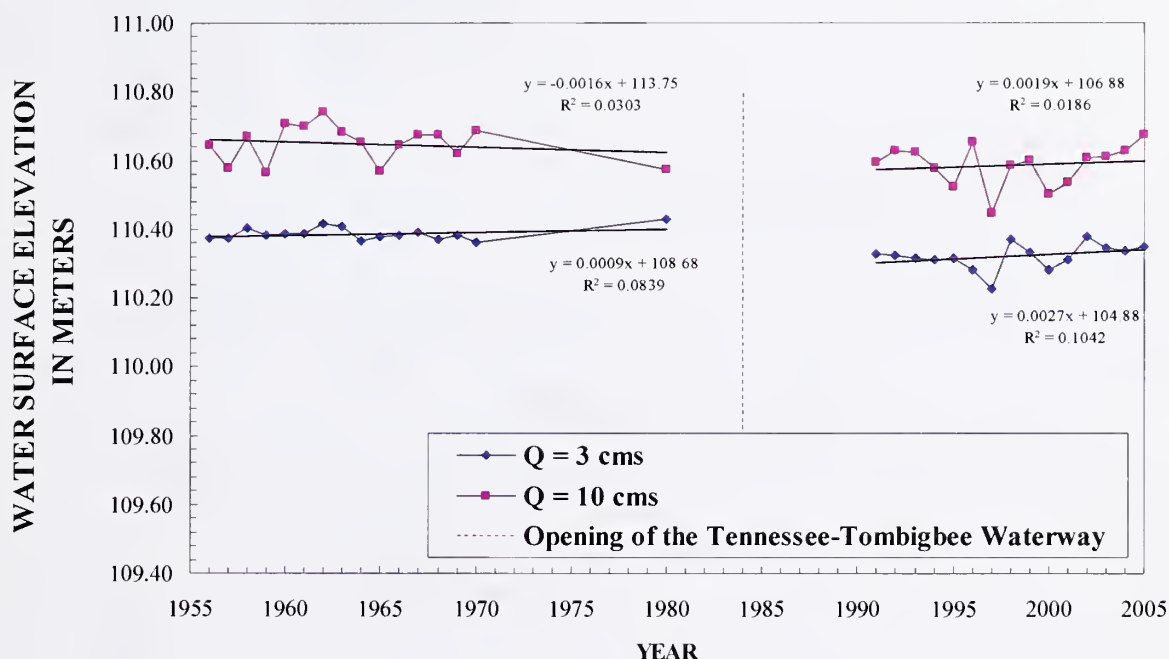


Figure 33 - A) Discharge-depth relation and B) discharge-width relation for USGS gage 02446500, Sipsey River near Elrod separated into different time periods.



**02438000 (Hamilton) Reach D: period of record 1964 to 2004**

Specific-gage analysis for the gage below Hamilton (rkm 116.5), Alabama shows little change over the period of record (Figure 34). Splitting the data set into pre- and post-TTW (Figure 35) as well as shorter periods also showed no distinct changes over the time period (Figure 36).



**Figure 34 – Specific gage analysis for gage 02438000, Buttahatchee River below Hamilton.**



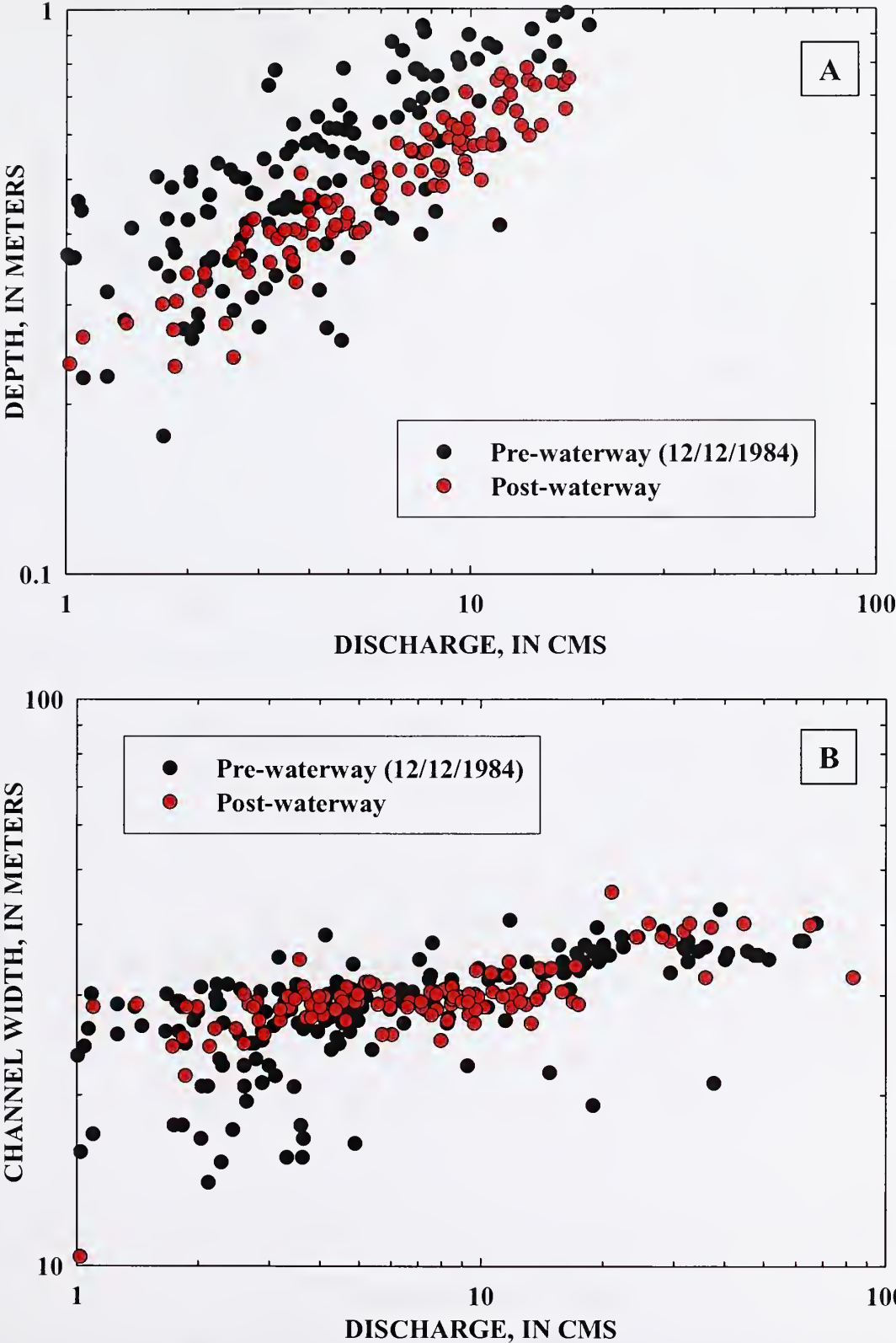


Figure 35 – A) Discharge-depth relation and B) discharge-width relation for USGS gage 02438000 Buttahatchee River below Hamilton for pre- and post-waterway.



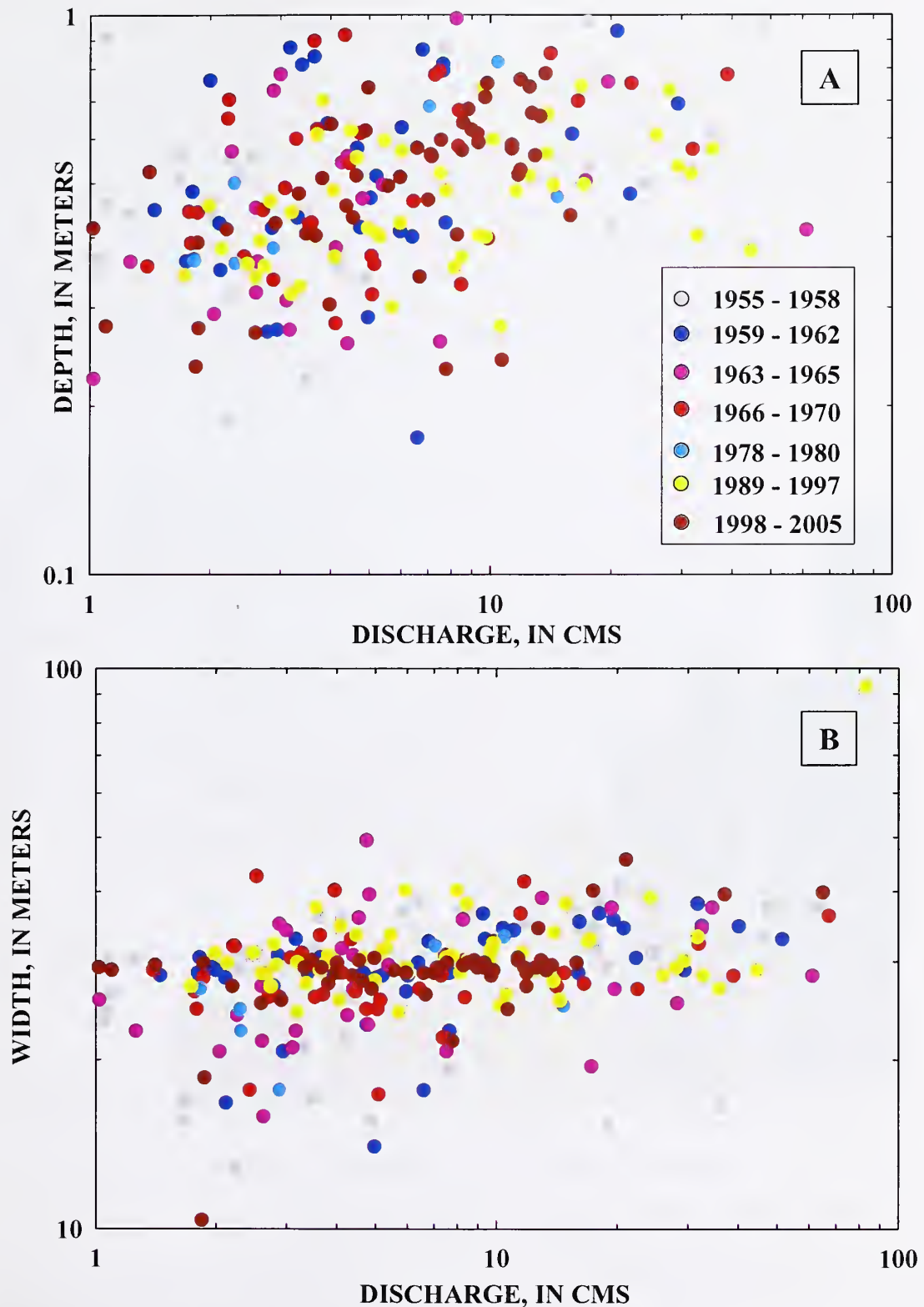


Figure 36 – A) Discharge-depth relation and B) discharge-width relation for USGS gage 02438000 Buttahatchee River below Hamilton separated into different time periods.



### 5.1.3 Suspended-Sediment Yield

Suspended-sediment yields (load divided by drainage area) for three sites within the Buttahatchee River Basin were compared to other gauged sites in Ecoregion 65 (Southeastern Plains). At only one site, Buttahatchee River at Aberdeen (02439400), were there a sufficient number of suspended-sediment samples ( $>30$ ) for calculations to be statistically relevant. For this site, the sediment yield at  $Q_{1.5}$  (effective discharge, Simon *et al.*, 2004) is 2.5 times greater than the median value for stable sites in the ecoregion (Figure 37). Sediment load per unit area is relatively high when compared to other streams in the ecoregion, which is not surprising given the instability of the Buttahatchee River. Similarly, mean annual suspended-sediment yield is more than twice the median for the Ecoregion ( $26.8 \text{ T/y/km}^2$  versus  $12.0 \text{ T/y/km}^2$ ).

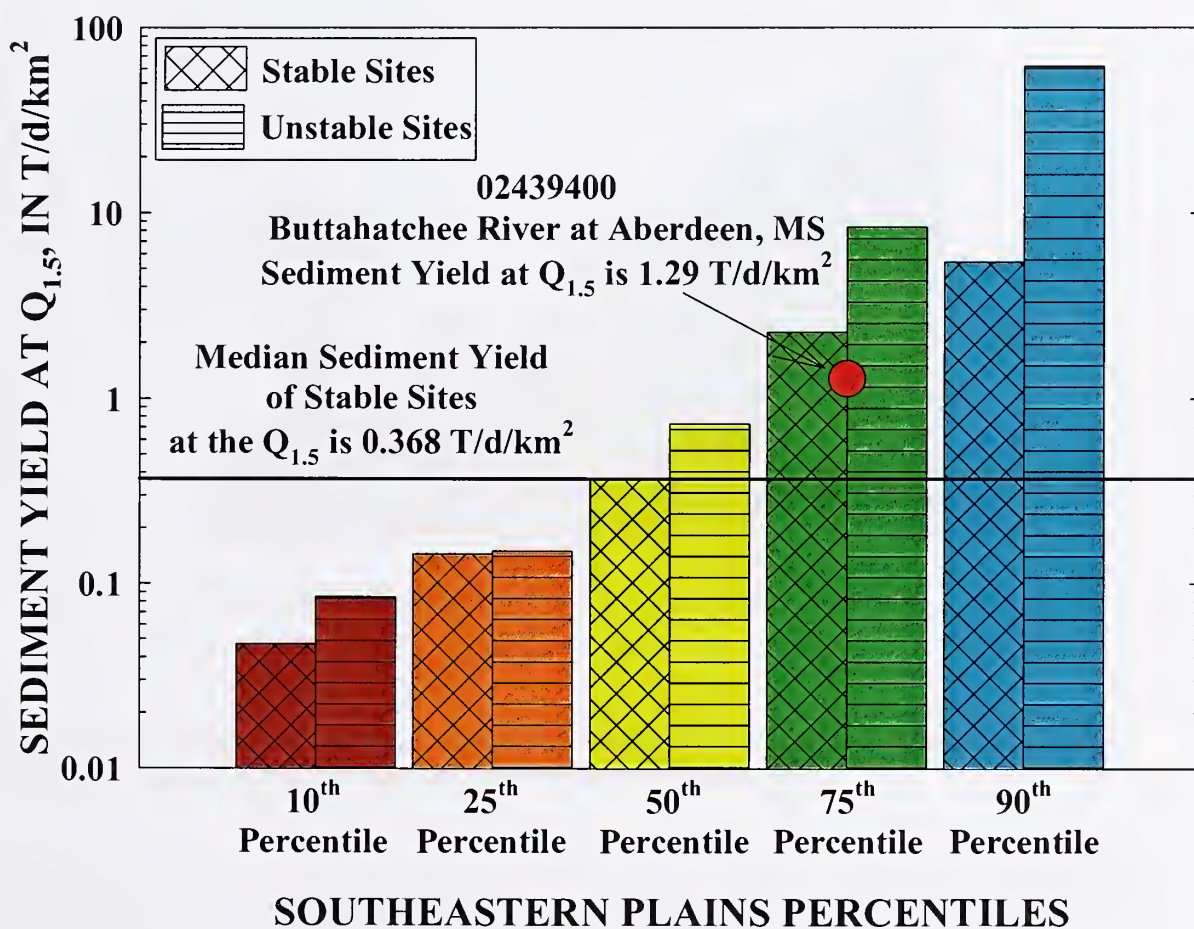
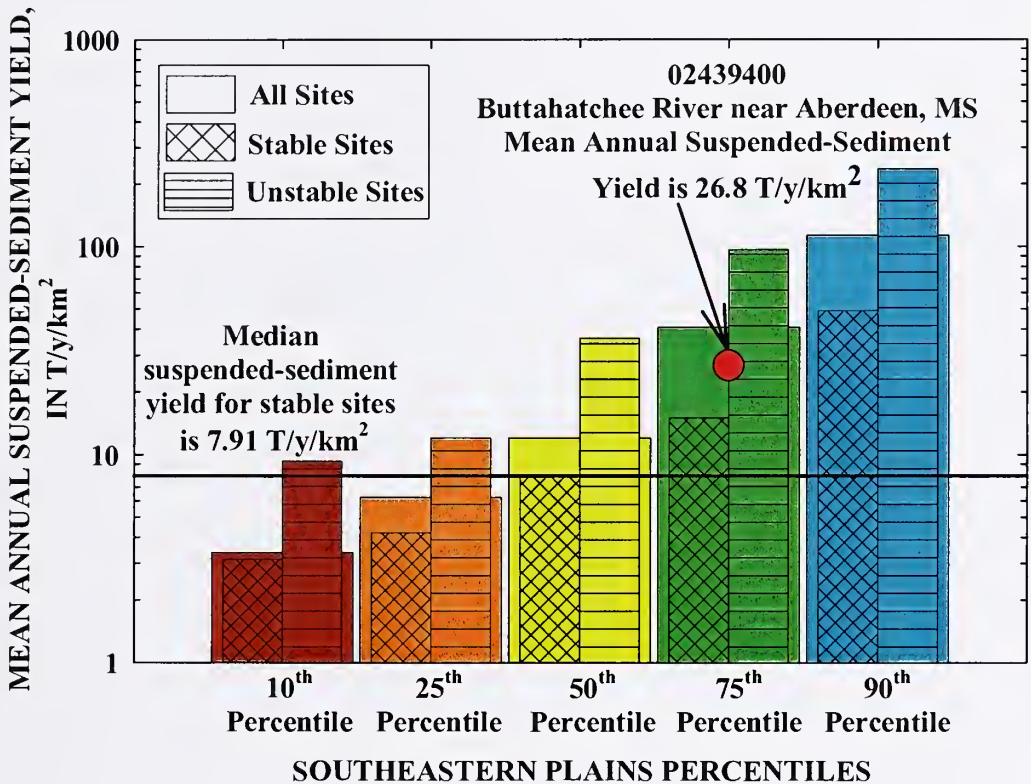


Figure 37 – Suspended sediment yield at the  $Q_{1.5}$  for the Buttahatchee River at Aberdeen, MS



Suspended-sediment yields calculated for the other two sites, Buttahatchee River below Hamilton (02438000) and Woods Creek near Hamilton (20437900) are an order of magnitude higher at the  $Q_{1.5}$ , 25.7 and 12.6 T/y/km<sup>2</sup>, respectively. Annual suspended-sediment yields are calculated as 106 T/y/km<sup>2</sup> for the Buttahatchee River below Hamilton, and 124 T/y/km<sup>2</sup> for Woods Creek near Hamilton (Figure 38). These results were generated with very limited suspended-sediment data (<10 samples per site) and should be viewed with caution. It can be stated, however, that even if these values are overestimates, the yields from these two sites are probably well above those for stable sites in the Ecoregion and represent unstable conditions.



**Figure 38 – Mean annual suspended sediment yield, as calculated from mean daily discharge data, for the Buttahatchee River at Aberdeen, MS**

Suspended-sediment yields over time were compared at gage 02439400, Buttahtachee River at Aberdeen (Figure 39). Sediment yields were separated into separate years of record (Figure 39A), and into the periods of air photo analysis (Figure 39B). The graphs show that sediment yield varied considerably from year to year, with the same peaks and troughs seen in the discharge data discussed previously. Dry years and wet years can thus be distinguished from the year by year analysis. For example the 1973 floods show a high sediment yield for 1973, and the relatively wet years of 1990 and 1991 also show as high sediment-producing years. In addition, the dry years of the late 1980's can be clearly seen. As sediment yield is calculated by applying the sediment rating curve for a



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particular gage to the discharge record at that gage, it is not surprising that trends in peak annual suspended-sediment yield mirror trends in discharge as seen in Figure 39A. In contrast to the annual suspended-sediment yield values separated out by year, values calculated for each of the periods of air photo analysis show that over each time period there was little change over time, although the data do show a slight increase in mean annual suspended-sediment yield during the 1981-1992 period, with slight attenuation of these values during the remaining two time periods. However, even though the attenuation of suspended-sediment yields for the later time periods is similar to the attenuation in widening rates, the former is related only to differences in discharge for each period.



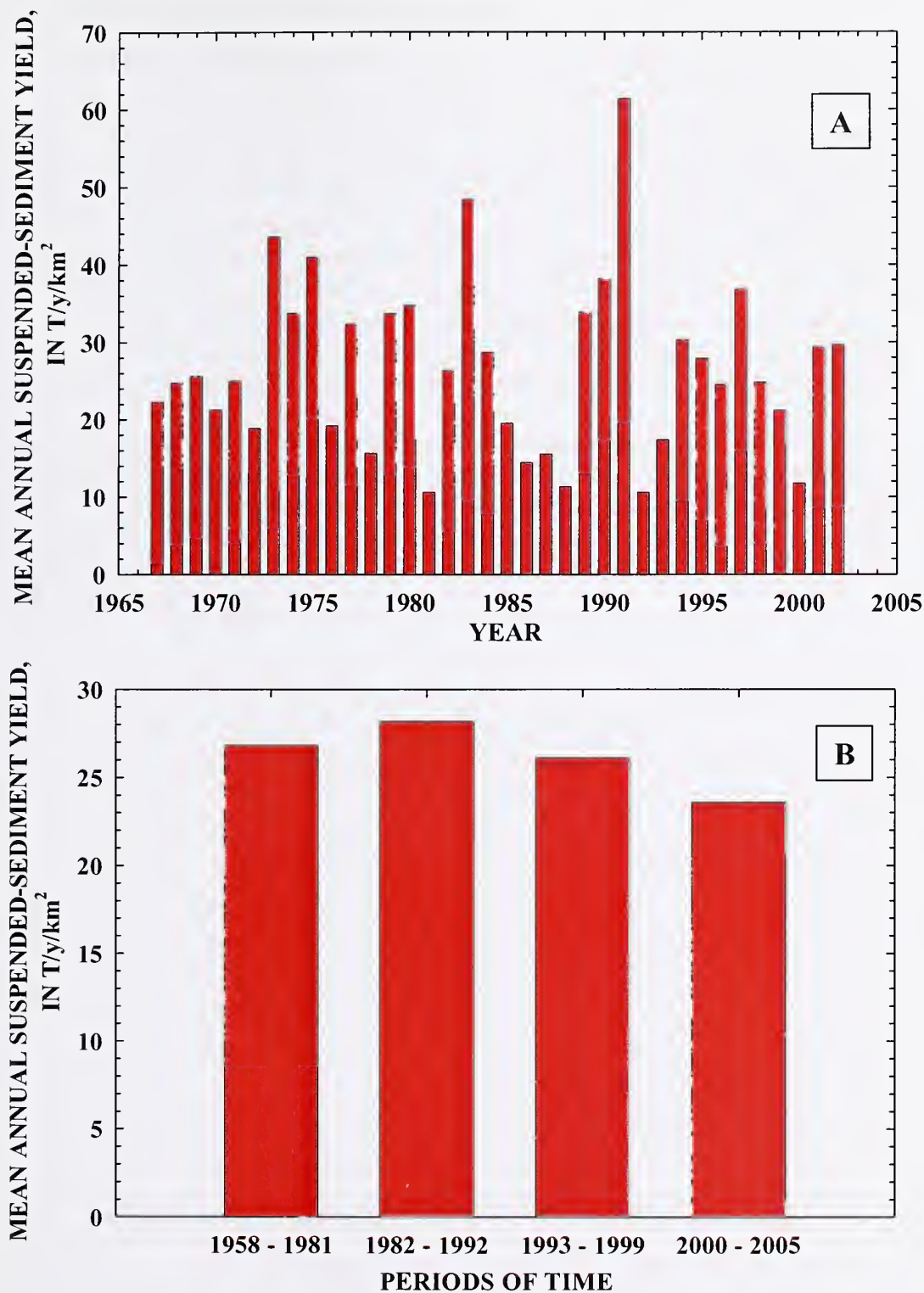


Figure 39 – Average annual suspended-sediment yield over time for the Buttahatchee River at Aberdeen. A) For each year of record and B) for each of the air photo analysis periods.



## **5.2 2005 Conditions of the Butahatchee River**

### **5.2.1 Rapid Geomorphic Assessments and Helicopter Reconnaissance**

The RGA's carried out on the Buttahatchee River showed that all of the sites were either at Stage V (unstable) or Stage VI (stable) (Appendix D). Of the 108 sites visited along the river, 18 were found to be stable, and 98 were found to be unstable (Figure 40). The sites in reach A that were found to be stable, occur at the location highlighted in the air photo analysis, where some channelization of the channel seems to have occurred pre-1958 (A24-A27). In reaches D and E, the stable sites were located in an area where the channel is dominated by bedrock and boulder/cobble bed material. The other stable sites seen on Figure 40 are located on tributaries of the Buttahatchee River, including the Sipsey River (seen joining the main channel between rkm 59 and 60) and Bear Creek.

The lower reaches of several tributaries were studied to see if the instability seen in the Buttahatchee River channel extended up into its tributaries. The RGA's indicate that the lower ends of the tributaries studied are also a combination of stage V and VI. Field notes for some of the tributaries joining the Buttahatchee River in reaches C and D state that the tributaries in this area are steep, and seem to contribute substantial load to the Buttahatchee River.



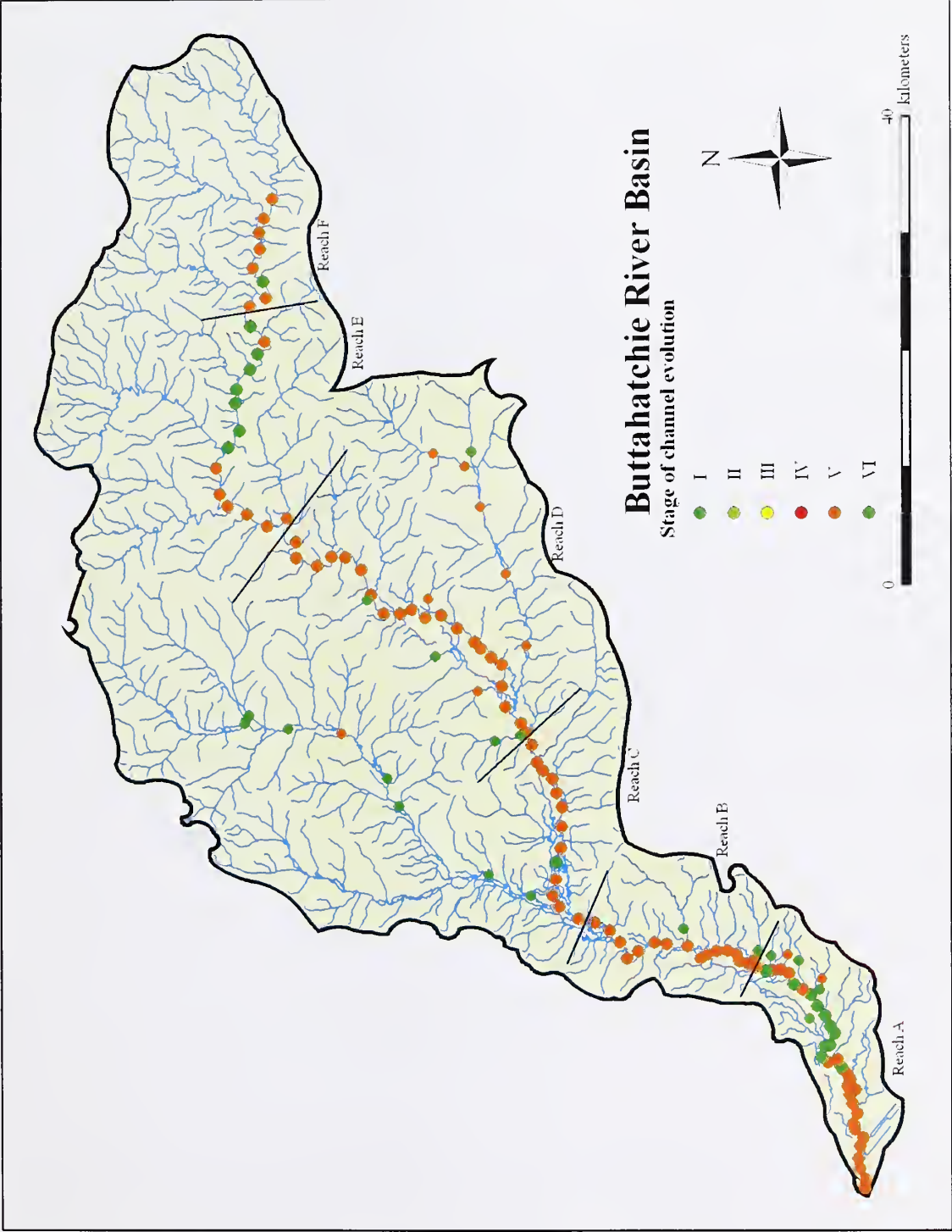


Figure 40 – Stage of channel evolution at each RGA site along the Buttahatchee River and its tributaries



**Table 9 – Rkm's for reaches A to F of the Buttahatchee River, with brief reach descriptions attained from information gathered during RGA's and helicopter reconnaissance.**

Reach	From Rkm	To Rkm	Description
A	0	34	Lower 1 km affected by Tenn-Tom impoundment (backed up water, higher water table). Middle part of reach affected by gravel mine capture with resulting ponding and unstable riffles especially below Hwy 45 bridge. Upper part of reach also unstable with a great deal of tree debris and depositional bars in channel. Bank faces are generally steep, bare and highly eroded. Bed material is dominated by gravels, with aggraded sand deposited on bars.
B	34	60	This reach shows signs of instability with streambank mass-wasting evident along entire reach, and trees falling in from the banks. Much debris and depositional bars in channel in this reach, with steep, bare banks in most cases. Bed material dominated by gravels.
C	60	81	Reach is unstable. Widespread evidence of mass wasting of banks, and trees falling into channel. Bed material dominated by sands rather than gravels seen in the lower reaches.
D	81	128	Large sandbars depositing on inner bends of meanders and eroding outer banks – meander belt is widening. Straight reaches between meanders seem to be a little more stable than the reaches downstream, but there is still much debris in the channel. Dominant bed material is sand.
E	128	158	There is evidence of instability in this reach (mass wasting, debris in channel), but erosion in this reach is more localized than lower reaches. Some parts of this reach have well vegetated banks, with an established shrub layer extending from bank tops onto bank faces at some locations.
F	158	172	Similar to Reach E – still signs of localized instability, but erosion is less extensive than lower reaches of this river, with well vegetated and less steep streambanks compared to the lower reaches.



### 5.2.2 Percentage of each reach failing

RGA results were used to obtain estimates of the percentage of each reach failing at each site visited. On each RGA form there is a section for the longitudinal extent of streambank instability, expressed as the percentage of banks failing (0-10, 11-25, 25-50, 51-75 and 76-100). At each site the values recorded on the data sheet were:

- Averaged to obtain an average percent of reach failing for each site (Figure 41)
- To illustrate the maximum value recorded for either the left or right bank (Figure 42).
- Used to obtain average values for each site to illustrate mean percent of reach failing for each of the reaches A-F (Table 10)

Figure 41 shows that the percent of reach failing at each site in A does not exceed 50% when both banks are averaged. In reach B, the majority of the sites have a percent of reach failing estimate of 25-50%, and one site has a value of 50-75%. Apart from one site in the lower part of reach C which has a value of 50-75% reach failing, the lower part of reach C seems to have lower percent reach failing values than reach B. However, the upper part of reach C and lower part of reach D have many sites where percent reach failing is 50-75%. One site in D has percent of reach failing in the highest category of 76-100%. High percent instability remains up into the middle of reach E, where the sites in the areas of rock outcrop are more stable. Upstream into reach F again the percent of reach failing mainly falls into the 26-50% category.

Figure 42 shows the maximum percent streambank instability at each site, and may be more useful in highlighting areas where streambank stabilization measures would be most effective. The lower 20 km of reach A, and large sections of reaches B, C and D have at least one bank (in general outside banks) where percent failing is 50-75%. The most unstable banks (76-100% failing) are located in the lower half of reach A, and in reach D. Tributaries appear to have relatively low percent reach failing at all sites visited. The lower part of reach A is particularly susceptible to severe bank erosion because of the disturbances that have affected this reach, including meander cutoffs between 1958 and 1981, impoundment of the TTW causing greater saturation of the banks and the capture of the gravel mines below the Hwy 45 bridge. In reach D, notes taken during the helicopter flight suggest that the outer bends of the meanders are the most unstable parts of this reach, with large sand bars being depositing on the inner bends and in the straight riffle areas, which seem to be experiencing less (but still some) bank erosion. The meander belt in reach D, therefore, seems to be actively widening, possibly as a response to the positive feedback loop established in this reach from an excess of sediment delivered to the channel from the uplands, forest clear cuts that occurred predominantly in the 1981 to 1992 time period, and agricultural land-use. This excess sediment is deposited on sand bars that then deflect flow at the meander bends in such a way as to increase bank erosion, and thus sediment delivery to the channel.

**Table 10 – Mean percent of reach failing taken from RGA sites in each reach.**

	A	B	C	D	E	F
Mean percentage of reach failing	43	44	42	55	23	35



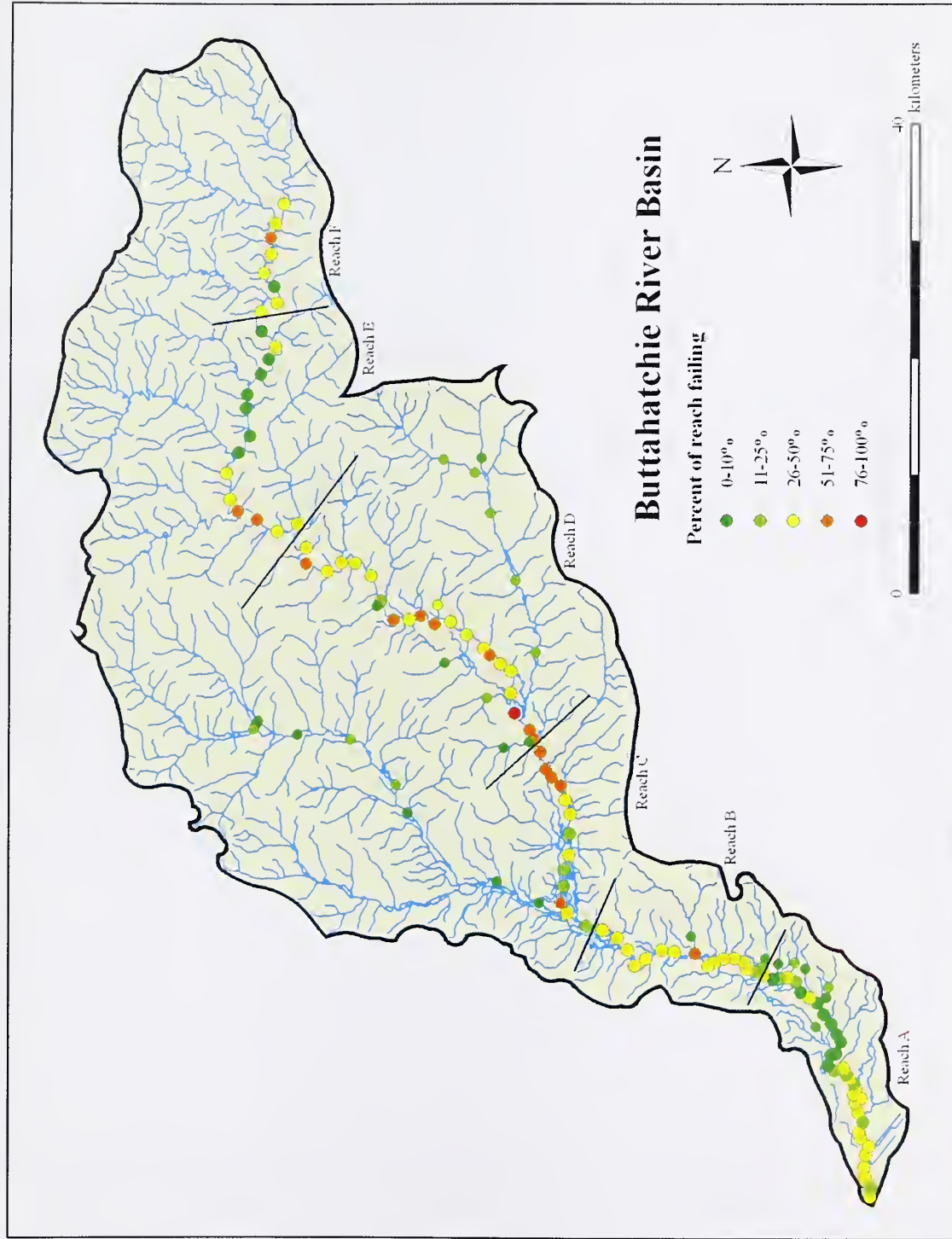


Figure 41 – Percent of reach failing at each RGA site along the Buttahatchee River and the lower ends of its tributaries



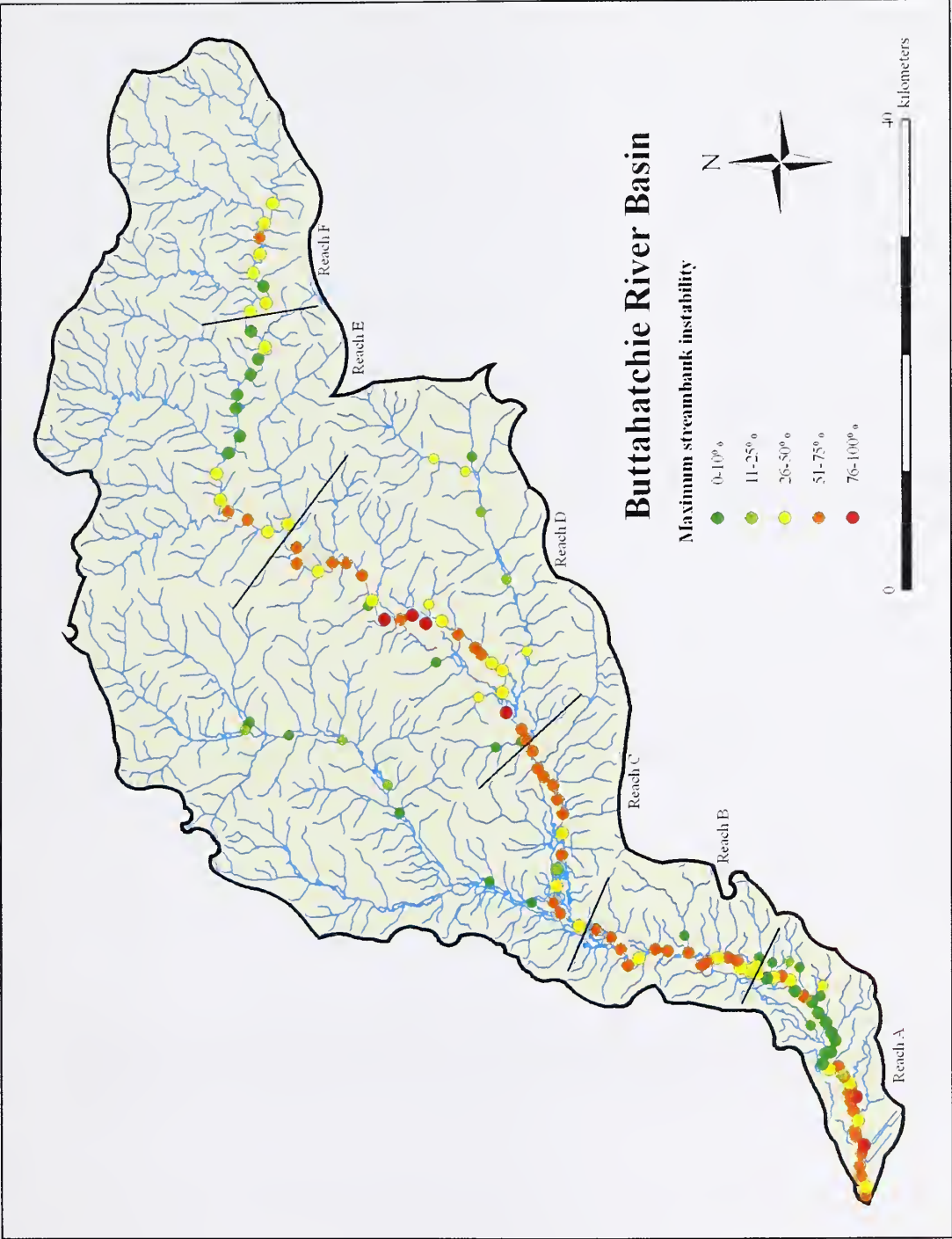
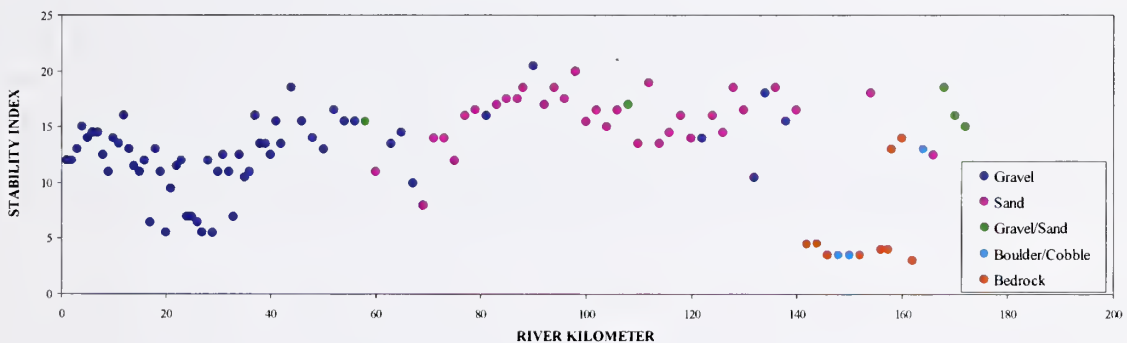


Figure 42 – Maximum streambank instability at each RGA site along the Buttahatchee River and the lower ends of its tributaries



Figure 43 shows the channel stability index obtained from RGA data, plotted against river kilometer, and separated by dominant bed material. It can be seen that almost all sites were found to be unstable (stability index  $> 10$ ), with a few sites in reach A being relatively stable (around rkm's 24-30) having undergone channel modifications in the past (see Section 5.1), and some sites in reach E being relatively stable due to the bedrock/boulder/cobble bed material. General instability exists at the remaining sites, with local peaks in instability occurring below rkm 10 in reach A (where disturbances have been concentrated), at rkm 44 in reach B, and at rkm's 90 and 98 in reach D. In reach C, between rkm's 60 and 75, the stability indices for all sites visited were below 15. Therefore, whilst these sites still exhibited moderate instability, this section of the river was more stable than many of the sites upstream and downstream. This stretch of the Buttahatchee River may not yet have experienced the upstream progression of instability resulting from disturbances in the A reach. As bank materials appeared to be fairly consistent across the samples taken at BST sites for reaches A to F (all containing high percentages of sand, with localized concentrations of gravel), the higher stability of these sites in reach C compared to upstream in reach D, may be related to land use changes within the Buttahatchee River watershed. Land use changes are discussed further in section 5.2.6. Rkm D98 is the area in which the large debris jam was recorded. Instability around this location was seen to be high because the log jam causes sediment to be trapped behind the debris, allowing the river to scour downstream of the debris jam.



**Figure 43 – Channel stability index for each RGA site, plotted against river kilometer upstream of the TTW, and separated out by dominant bed material type. Dashed lines indicated those sites that are stable (index  $< 10$ ), and unstable (index  $> 10$ ).**



### 5.2.3 Bed material composition

RGA's showed that the beds of Reaches A and B are dominated by gravels (Figure 44, Appendices C and D), although bars in these reaches were composed of a mixture of sand and gravels. The partially armored gravel beds seen in these reaches are features of scour, and indicate that the channel in these reaches has sufficient energy to transport finer material through most of the thalweg, with deposition of finer sediment occurring mainly on bars. At some sites (particularly above Hwy 45 bridge and up into Reach B), gravel clasts were stained black with a manganese oxide which has precipitated from ground and stream waters (Patrick *et al.*, 1996), indicating a relatively stable bed. In reaches A and B, even where gravel dominates, aggradation is a common feature, with large deposits accumulating as bars, thus increasing the energy in the deeper areas where flow is deflected, maintaining the gravel bed. One cause of aggradation in the lower reaches has been the impoundment of the Columbus Pool, and the resulting raising of the base level of the Buttahatchee River. In addition, the large amount of sediment being delivered to the lower reaches from streambank instability and land-use issues in the upper part of the watershed also contribute to the inability of the channel to transport all of the sediment.

Bed material of Reaches C and D were dominated by sand, with occasional areas dominated by gravel. There was generally a much greater percentage of sand on the channel bed through reaches C and D, than in the lower reaches A and B. The two main tributaries of the Buttahatchee River in the C and D reaches (Sipsey and Bear) also had bed material largely composed of sand, and it is therefore possible that these tributaries and their associated uplands deliver a significant source of sediment to the main stem of the Buttahatchee River. A preliminary sediment-load report by McGregor and Cooke (2005) for the Buttahatchee River stated that much of the fine sediment load in the Buttahatchee River originates in the upstream part of the watershed, with their data showing that as watershed area decreases upstream, the sediment yield increases.

In addition, bank instability is also occurring throughout reaches C and D of the Buttahatchee River, so some of the sand found on the bed there is coming directly from the banks themselves. (the bank materials in all the reaches contain high percentages of sand with gravel deposits also present at some locations) At some locations in reaches C and D, gravel was found in larger quantities on the bed which may suggest that there is gravel underneath all of the sand bed material, but sampling in this study was unable to confirm this. The large amount of sediment present in the upper reaches of the Buttahatchee River, particularly in reach D, seem to largely be a result of changes in land-use in the upper reaches over the period of time studied, including logging and increased agricultural production. The aggrading sand bars and the presence of sand on the bed of the main thalweg infers that the channel does not have enough energy to transport all of the sediment entering the system in these reaches. A positive feedback loop is occurring in many locations as the accretion of bars deflects flow to the outer meander banks, thus leading to bank erosion and failures, delivering further sediment to the channel.



The RGA's also revealed a large debris jam at site rkm D98. (Figure 45). This debris jam could have caused increased deposition of sediment behind the debris jam, and increased erosion and scour downstream of the debris jam because of the reduced sediment concentration, and therefore increased eroding potential of the flow. The logs that create the jam are likely to have originated from the banks of the upstream reaches, particularly the outer meander bends of the unstable parts of the D reach (rkm's 105 to 113 and 117 to 121). Such debris jams can cause local bank erosion as the logs tend to deflect the flow towards the margins of the channel, leading to accelerated lateral erosion of the channel. As discussed earlier, this is one possible explanation for the rapid widening seen at site D108 between the 1958 and 1981 air photographs.

Photos taken during the helicopter flight over the upper part of reach F and into the headwaters of the Buttahatchee River also showed a large amount of fine sediment in the Buttahatchee Lake. Parts of Reach E were underlain by bedrock with boulders and cobbles also present at some sites. Reach F had a mixture of bed materials including boulder/cobble beds, sand- and gravel dominated beds.



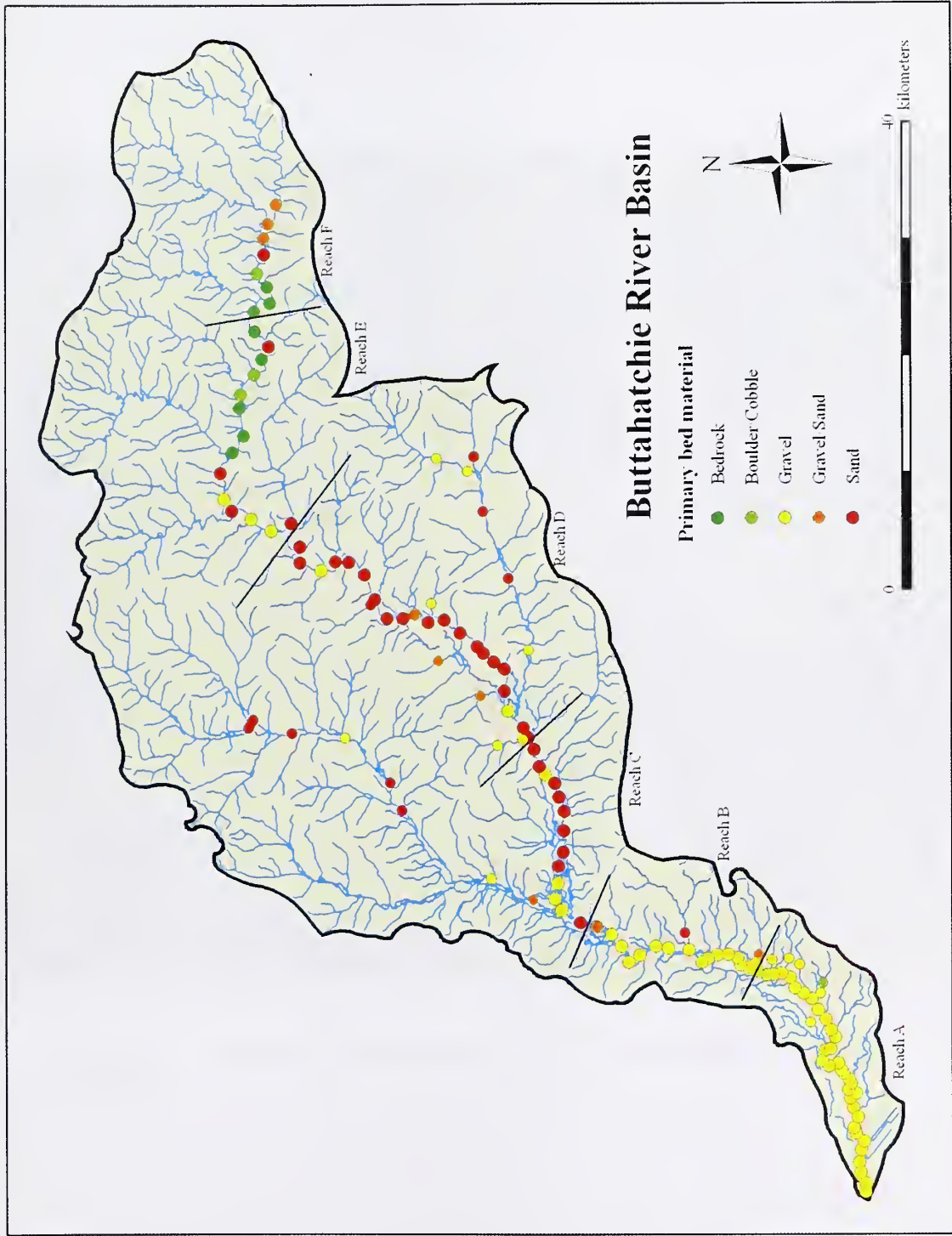


Figure 44 – Dominant bed material at each RGA site along the Buttahatchee River, and selected tributaries.

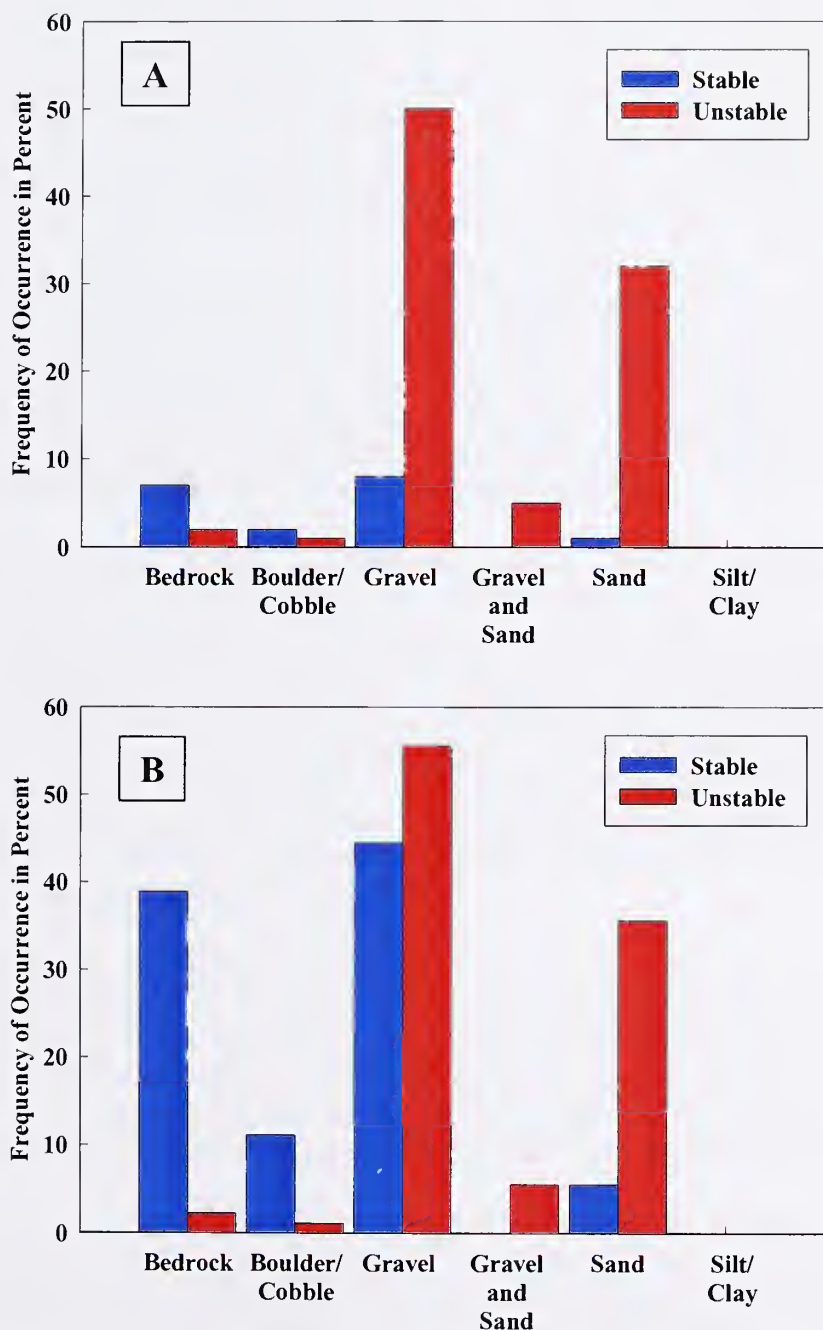




**Figure 45 – Log jam in the Buttahatchee River at rkm D98, estimated at 100-200 m in length.**



Bed material was compared for stable versus unstable sites. As there were very few stable sites compared to unstable sites, two graphs are presented in Figure 46: A shows the actual number of sites with each dominant bed material and B shows the percent occurrence of each bed material type for stable and unstable sites. All but one of the stable sites had bed material dominated by gravel, boulder/cobble or bedrock (Figure 46A). The unstable sites predominantly had bed material composed of gravel and/or sand.



**Figure 46 – Bed material at stable and unstable sites on the Buttahatchee River A) frequency of occurrence and B) Percent frequency occurrence.**



#### 5.2.4 Bank stability analysis:

Bank-stability analyses were carried out for a representative site in each of the reaches A to F, to quantify bank stability conditions for a range of steady state flow and water table heights. Results of these analyses can be used to determine critical conditions for stability and under what conditions the banks become unstable. Bank geotechnical properties were obtained from BST results and soil coring during testing (Appendices A and B). Each cross section was surveyed to provide bank geometry coordinates as input to the bank stability model (Appendix A). Model runs were carried out at varying flow depths and water table heights to simulate the full range of bank stability conditions between worst- and best-case scenarios. Best case conditions generally occur either when flow depth and water table height are both low, or when water table is low and flow depth is high (confining force from flow provides stability). Conversely, worst-case conditions for bank stability generally occur when water table height is high and flow depth is low. Such conditions tend to occur during the falling limb of a hydrograph, when the banks have become saturated, and the flow recedes, removing the confining force from the flow, and decreasing bank stability. The ranges of streambank Factor of Safety values are shown in Figure 47: The factor of safety is a quantitative expression representing the resisting forces divided by the driving forces. A value greater than 1.0 indicates stability while a value less than 1.0 indicates instability.

The bank stability results indicate that the banks tested at sites A28 and B42 were either conditionally stable or unstable under the widest range of flow and water table conditions. Indeed, for these two banks, the only times that banks were predicted to be stable were under high flow conditions at which time the confining pressure from the flow provides a stabilizing force to the bank. The upper part of the A28 bank profile was predominantly sand, containing some gravels and a small proportion of clay. High apparent cohesion in the uppermost layer (10.0 kPa, 0 - 0.36 m) decreased in the second layer as gravel and sand content increased. The bank layer at the base of the bank was dominated by gravel and sand, providing little cohesive support to the bank and a layer susceptible to undercutting by hydraulic forces.

The B42 profile was also dominated by sand, but contained little or no gravel. The samples taken yielded 94.1 %, 98 % and 98.6 % sand for 3 distinct layers (0 – 0.3 m, 0.3 to 1.45 m and 1.45 to 3.0 m respectively). BST tests showed the soil had low cohesion to a depth of 1.45 m (2.0 kPa apparent cohesion and 0.32 kPa effective cohesion) and then no cohesion in a sandy unit below 1.45 m; the high proportion of cohesionless sand in this profile contributes greatly to the instability predicted from the model runs at this site.

The banks tested at A10, C71 and D88 were generally found to be stable, until water table heights rose to 75 % of the bank height, at which point bank resisting forces are decreased sufficiently by the generation of pore-water pressures, for bank failures to occur even under high flow conditions. Only at 95 % bankfull flow depths does the confining pressure from flow overcome the decreased resistance from saturation and decreased resistance of the bank material from the higher water table.



If sites tested are representative of the reaches they are located in, results would suggest that upper reach of A through reach B are currently the most unstable parts of the Buttahatchee River. Indeed, the RGA results do show that problem areas exist in reaches A and B, but they also suggest that areas of instability in the Buttahatchee River extend up into reaches C and D, with the worst areas of streambank erosion on the maximum streambank instability figure (Figure 42) arising in the bottom half of reach A and within reach D.

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**Figure 47 –Factor of safety values for varying flow depths and water table heights for representative sites in each reach of the Buttahatchee River (green indicates stable conditions, orange conditionally stable and red unstable bank conditions).**

Increasing the relative stability of these banks is a matter of decreasing bank angles and thereby decreasing the driving forces, or conversely, increasing the resistance of the banks to mass failure. This can be accomplished by protecting the bank toes from hydraulic erosion and undercutting using rock or other materials that deflect flow or by increasing the geotechnical strength of the banks. The latter option can sometimes be accomplished by the planting of riparian vegetation, which provides reinforcement through the establishment of a root-soil matrix.



### 5.2.5 Land Use Analysis

The GIS layer for 1999 land use was analyzed to try to assess how land use in the Buttahatchee River Basin affects channel processes. Maps of land use for each reach are shown in Figures 40 – 45. The land-use was analyzed to calculate the percentage of land use in each category (see Figures 49 – 54 for full list of categories) at 1 km and 50 m either side of the Buttahatchee River. In this way it was possible to quantify land use categories closely and directly affecting the channel.

The analysis for 1 km either side of the Buttahatchee River (Figure 48A) showed that reach A was predominantly farmland (pasture and row crops, percent cover = 32.4 %) and wetland (percent cover = 35.3 %). The amount of agriculture in reach B was less extensive than in reach A (19.1 %), with increasing percentages of forest and wetland (28.0 % and 52.5 % respectively) compared to reach A. In reach C the percentage of forest decreases from reach B (to 24.5 % forest cover), but the percentage covered by wetlands continues to increase to 63.7 %. In reaches D, E and F up to 1 km from the river the percentage cover of wetland dramatically reduces to below 25 % in reach D and less than 0.5 % in E and F. Conversely, percent forest cover increases from 24.5 % in reach C to 51.5 % in reach D and then continues to increase through reach F where it reaches a maximum of 73.2 % of the land use. The analysis also shows that mining is only present 1 km from the channel in reaches A and in E, where some old kaolin strip mines are present. In the past these kaolin strip mines have contributed a great deal of fine sediment to the Buttahatchee River, (McGregor and Cook, 2005), but the present day effect of these old mines is less clear. The land use analysis at 1km from the channel confirms to some extent what would be expected: further upstream the percentage of land covered by wetland decreases as the floodplain narrows. It is also unsurprising perhaps that the percentage of land covered by agricultural land use is at a maximum in reach A, where the floodplain is at its widest, thereby providing much flat land with alluvial deposits suitable for farming. At the 1km scale the least agricultural land is in reach C.

The second analysis for 50 m either side of the Buttahatchee River showed similar trends in land use to the 1 km analysis, but with some interesting features (Figure 48B). Wetland dominated the land use cover for the buffer in reaches A, B and C. Therefore, although the percentage of land use covered by agriculture was highest in reach A in the 1 km analysis, the land use in the buffer 50 m from the channel is predominantly wetland, with little agriculture reaching right up to the edges of the channel. The presence of wetland through much of the buffer zone should reduce sediment from agricultural runoff reaching the channel.

As in the 1 km analysis, wetland cover reduces dramatically upstream into reaches D through F, with a corresponding increase in forest cover. The interesting difference in the land use in the river's buffer zone, is that in reaches D, E and F, the percentage of agricultural land use extending up to the channel increases from 0.22 % in reach C, to 4.46 % in reach D and up to 7.0 % in E and F. Although these percentages are small compared to the percent forest cover in reaches D to F, it is possible that this change in



land use could have significant effects on the amounts of sediment being delivered to the channel. Without a riparian buffer, banks are more susceptible to bank instability as there is no root-reinforcement to add to the cohesive strength of the bank materials, and no vegetation to intercept and modify infiltration and runoff patterns. This may in part help to explain the high percentage of fine grained bed material found in reaches C and D.

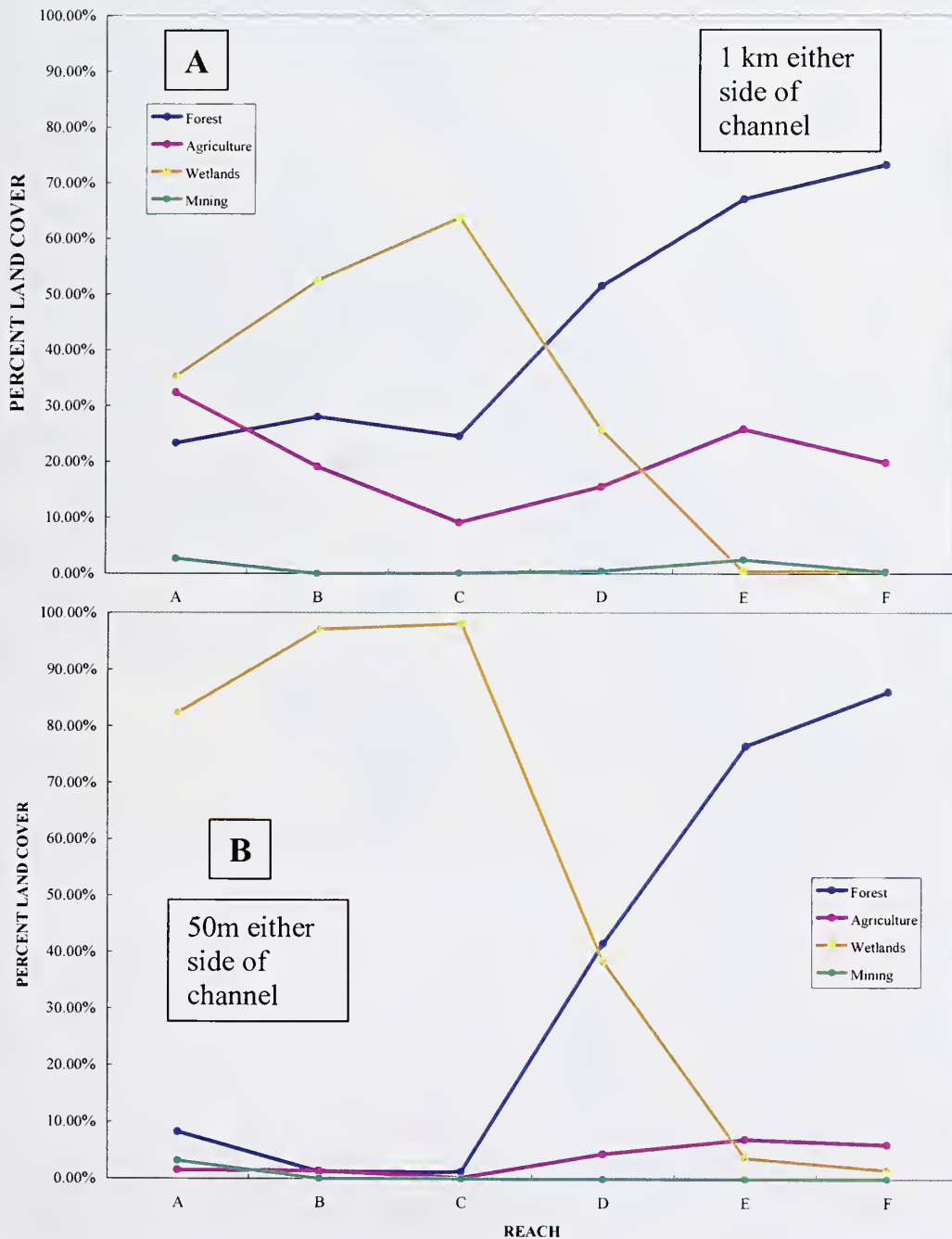


Figure 48 – Percentage land use cover, A) 1 km from the channel, and B) 50 m from the channel.



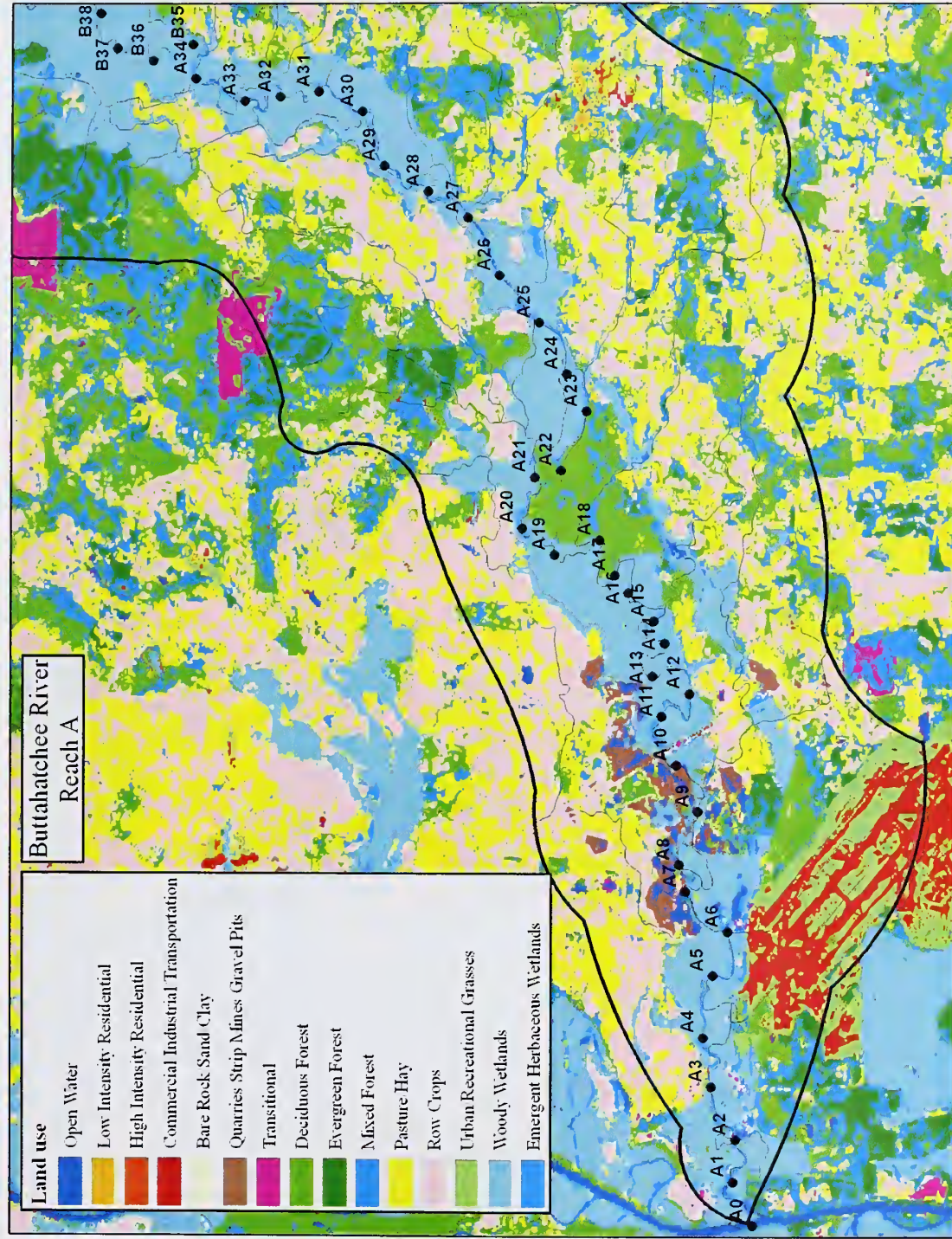


Figure 49 – 1999 land use for reach A.



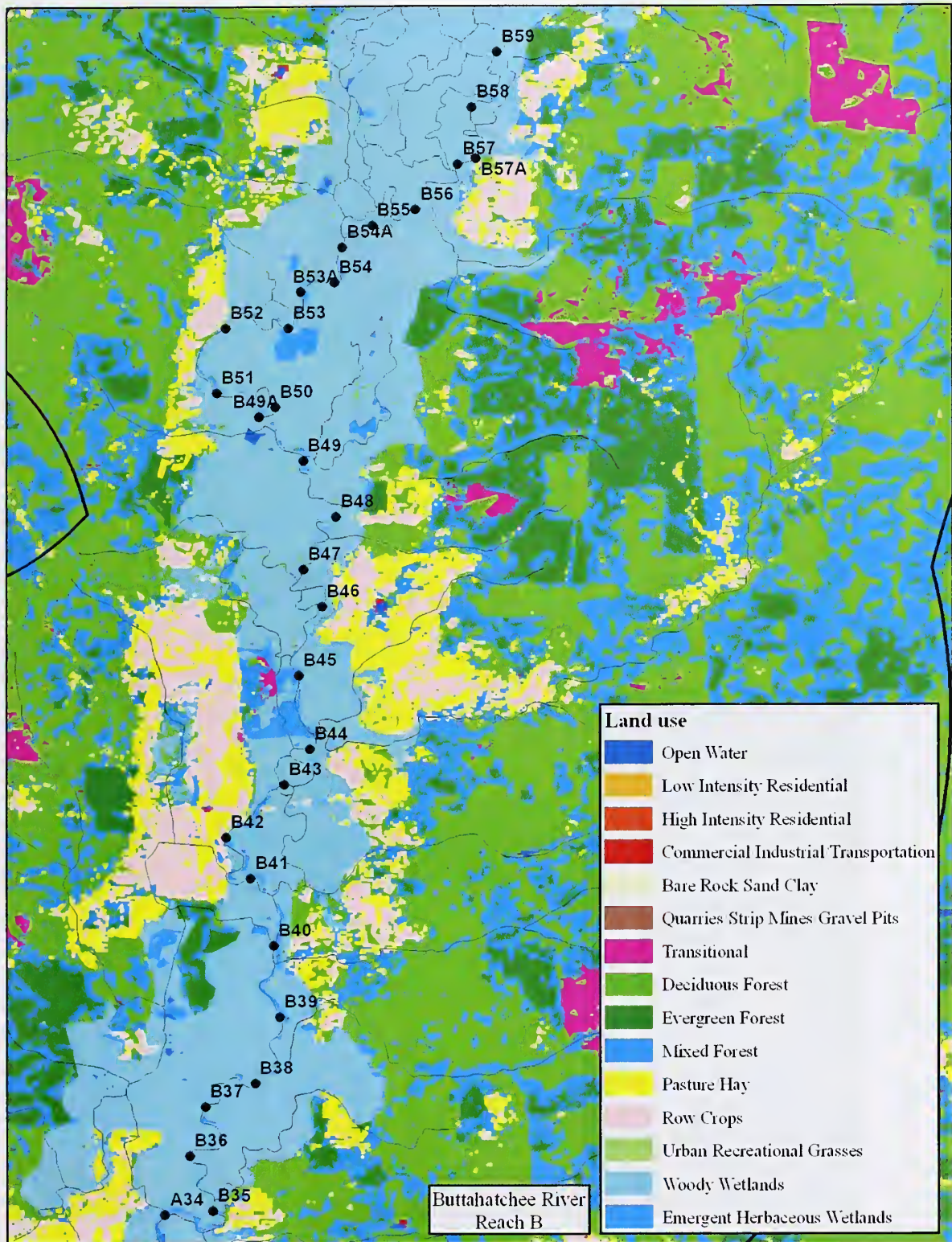


Figure 50 – 1999 land use for reach B



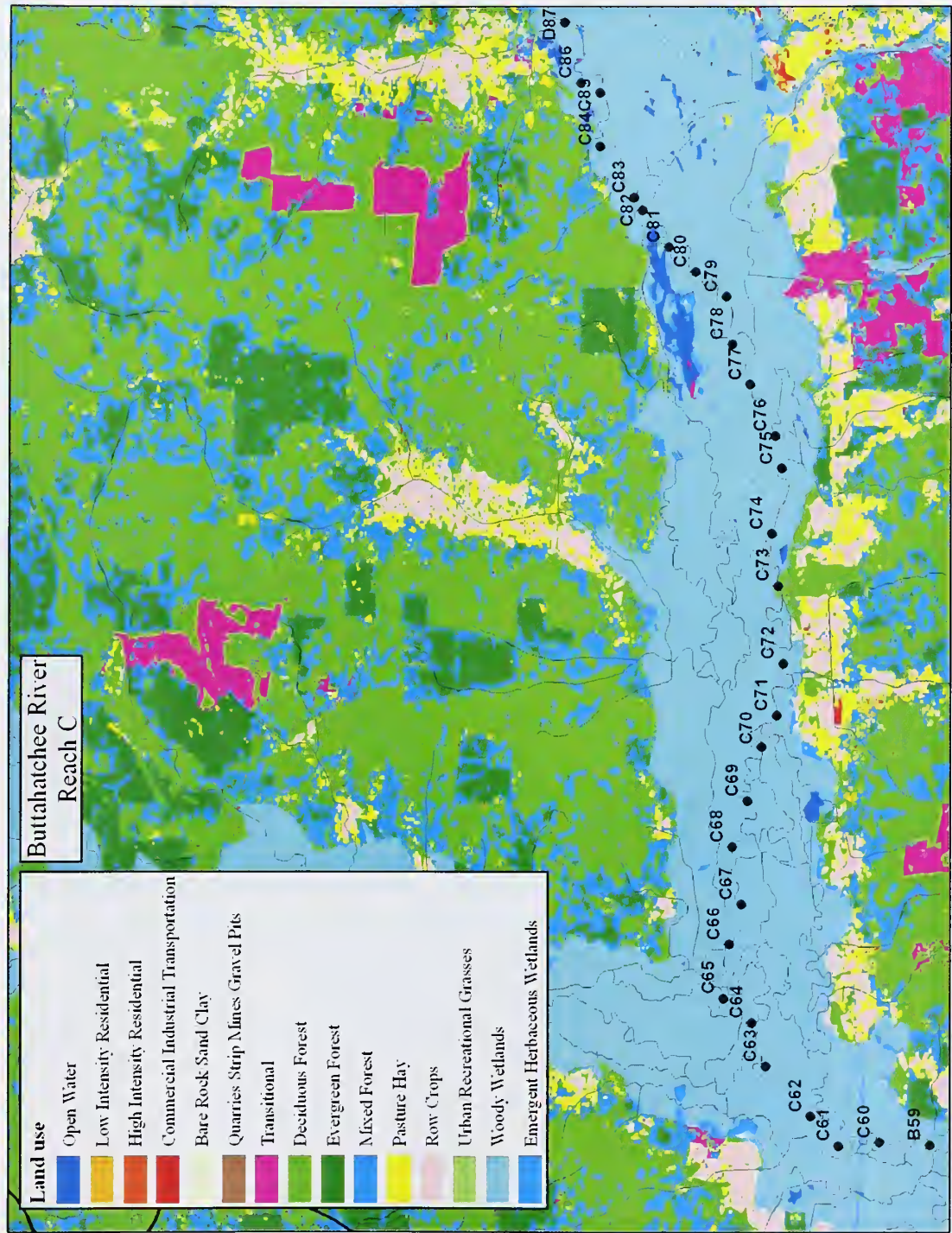


Figure 51 – 1999 land use for reach C.



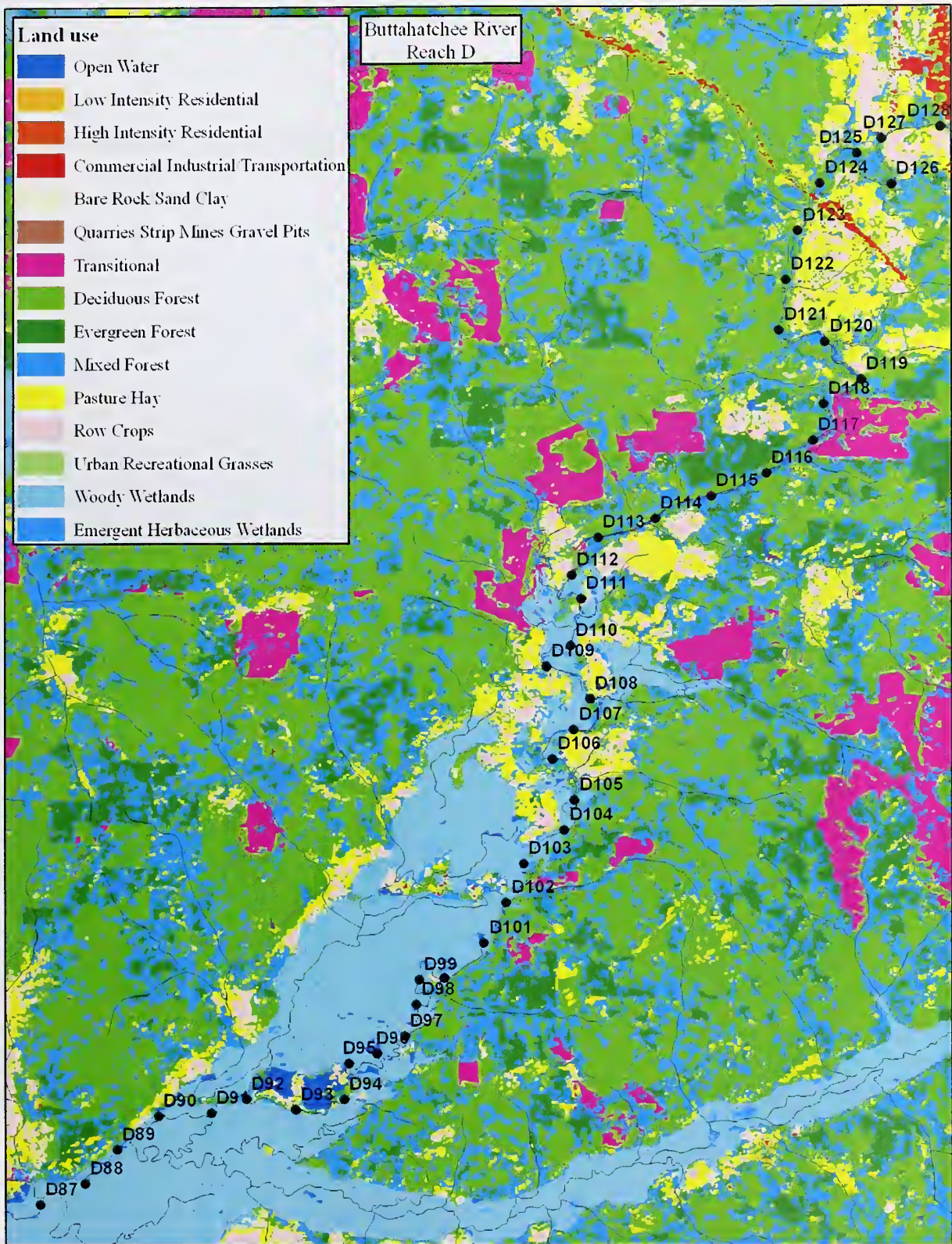


Figure 52 – 1999 land use reach D.



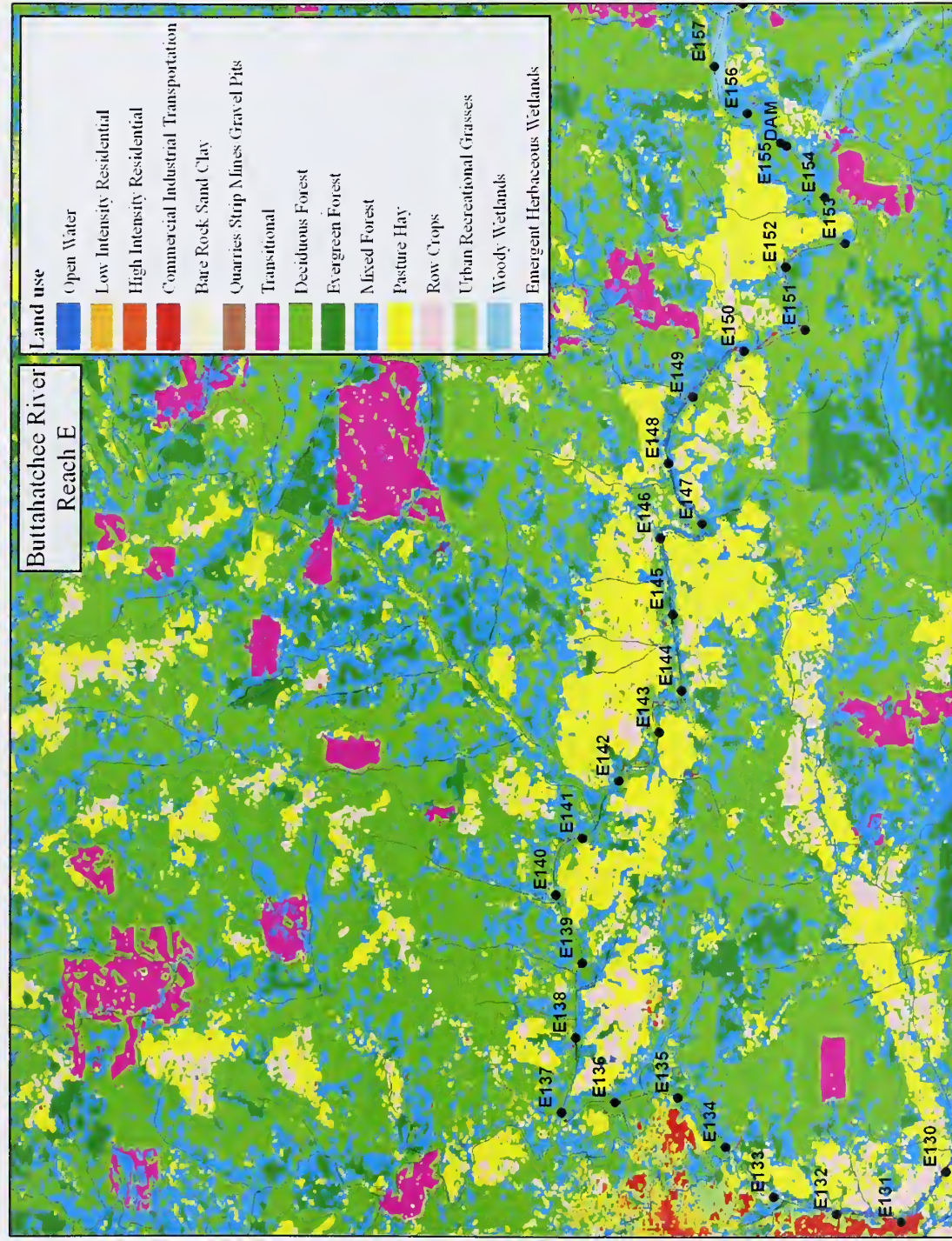


Figure 53 – 1999 land use reach E.



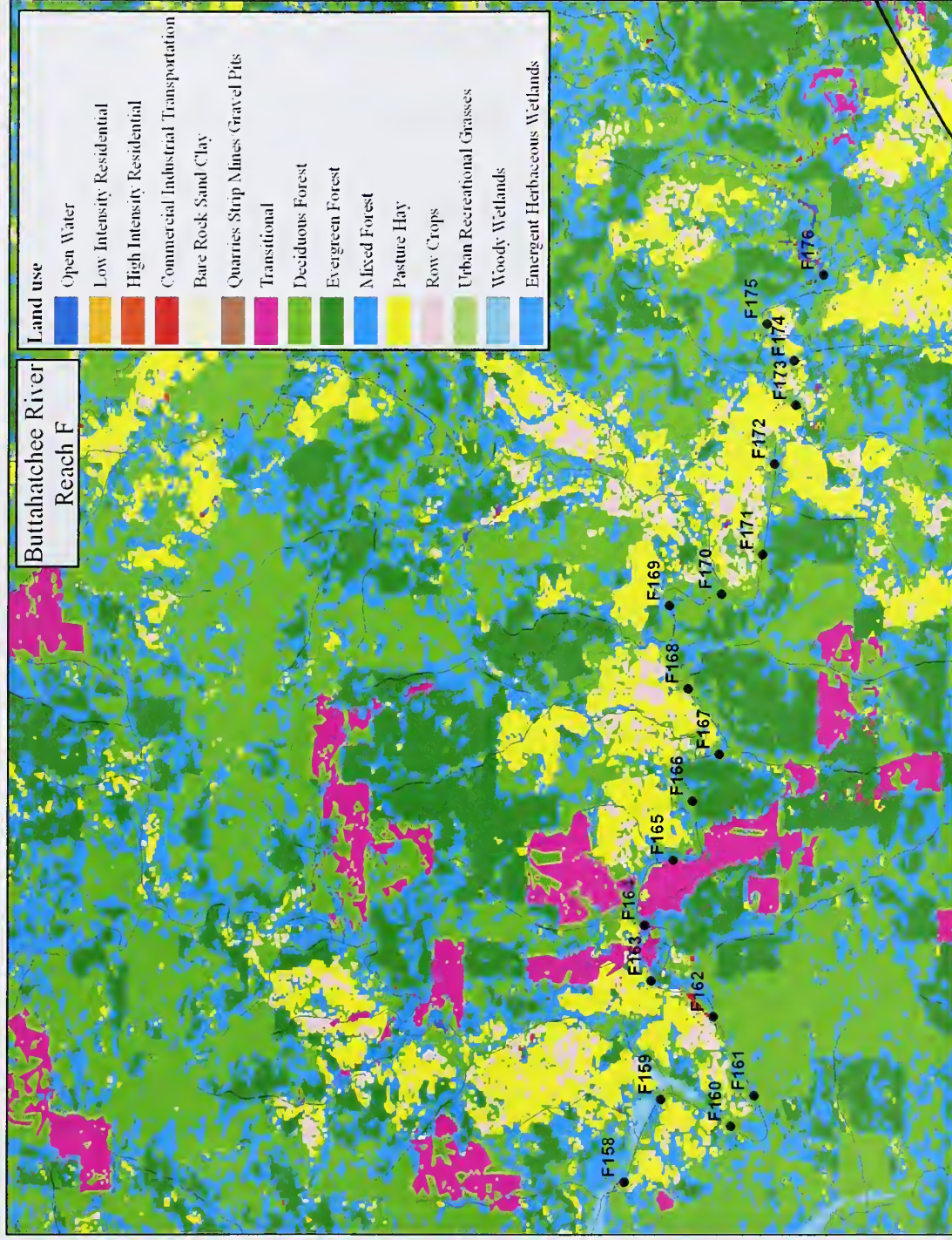


Figure 54 – 1999 land use reach F

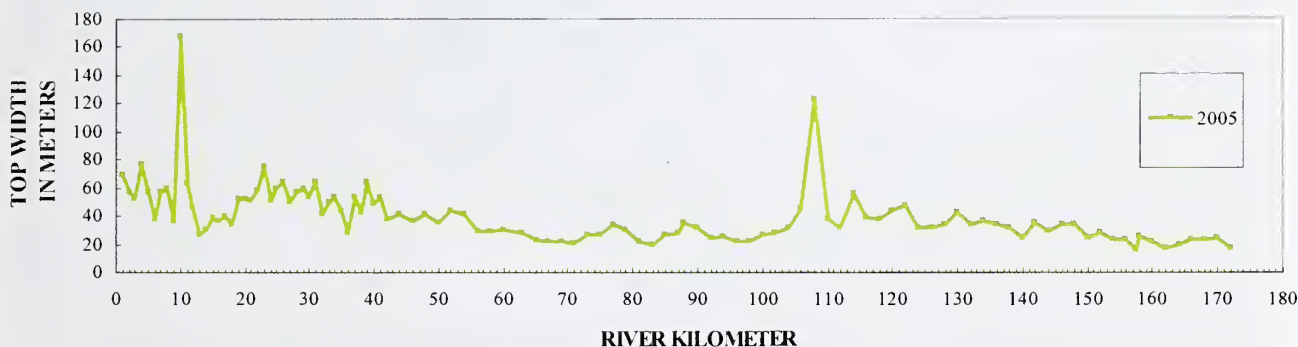


### 5.2.6 2005 Bank Top Widths:

2005 Bank top-widths show a general decline from the mouth of the Buttahatchee River to the headwaters, but local variations in channel stability (for example in Reach D) lead to some deviations from this general trend (Table 11; Figure 55).

**Table 11 – Average bank top-widths for Reaches A to F of the Buttahatchee River.**

Reach	Average top width (m)
A	55.4
B	41.8
C	25.5
D	38.5
E	31.2
F	21.6



**Figure 55 – Bank top-width for rkm 0 to 172 (Reaches A to F) of the Buttahatchee River.**

A large change occurs in top-bank width at approximately rkm 106 (Figure 55). Downstream of this point the channel widths attenuate, generally showing a decreasing trend moving upstream from the mouth of the Buttahtachee River. In reach D, top widths seem to increase suddenly (Table 11) and then attenuate again upstream. This change in channel top widths is a pattern that can be seen in all of the air photos, dating back to 1958, but the pattern becomes more distinct after localized erosion occurring sometime during the 1958-1981 period. The explanation for these increases in top width in reach D can be explained when a number of factors are considered.

One point that stands out on Figure 52 (land use for reach D) is that there seems to be a sudden change in land use types at approximately rkm 112. Upstream of this point the land use cover category ‘woody wetland’ is no longer present, indicating that there may be a change in topography at this point that restricts the extent of the floodplain and the formation of woody wetlands. A look at the topography for this reach confirms this change: A narrow valley exists between rkm’s 114 and 119, but around rkm 114 the river



enters a region of open alluvial floodplain (Figure 56). During high flows, water is constricted from rkm's 112 to 117 by the steep topography adjacent to the channel, but at rkm 112, the narrow valley opens out again and the floodwaters can spill out onto the floodplain, depositing alluvial material. These alluvial deposits and flatter topography make ideal agricultural land, and in this reach current agricultural land use is indeed concentrated from rkm's 103 to 114 and then again from 119 and upstream. Analysis of the aerial photography also shows that there has been an increase in the amount of land cleared for agriculture and logging over the 35-year period of study in this reach. The timing of increased erosion in reach D points to changes in land use being a dominant control on widening rates in this reach. Downstream of approximately rkm 104, agricultural land use close to the channel is reduced considerably, and Figure 55 shows that downstream of this point, channel widths are narrower again, supporting the idea that land use in reach D has an important control on channel morphology.



**Figure 56 - Topographic representation of rkm's 112 – 128 in reach D, showing the transition of the narrow valley at rkm 115-119 to the open alluvial floodplain both up- and downstream.**



## Considerations of Mitigation Alternatives

Instability in the Buttahatchee River is system wide, although local variations do occur and the degree and causes of instability vary. Localized mitigation of streambank instability would be best focused at sites where banks are most active and the highest percentages of banks failing were recorded in the 2005 RGA's. However, the problem with individual site modification is that stabilization of one site may deflect the eroding potential of the river further upstream or downstream. The responses to meander cutoffs and gravel-mine capture in reaches A through C will be difficult to mitigate as bank instability in the Buttahatchee River is extensive. Although wholesale re-patterning of reach A might seem a logical mitigation strategy to enhance downstream stability, detailed numerical modeling of alternative mitigation strategies is imperative to reduce uncertainty in the effects of any restoration effort. It is not uncommon for stream restoration efforts to lead to further instabilities if not properly planned and analyzed. The CONCEPTS channel evolution model (Langendoen, 2000) has been used, sometimes in combination with the upland model AnnAGNPS (Bingner and Theurer, 2001), to quantify loadings of sediment over time and the effects of various mitigation strategies.

There is no substitute for the time and space required by the channel to attain a new quasi-equilibrium following disturbances in reach A over the past 35 years. The channel instability and aggradation seen in the upper reaches of the channel are associated with the channel adjustments downstream to some extent, but in addition, land use in the upper part of the watershed maybe contributing to the problems.

Reduction in the sediment being introduced into the channel in reaches C and D could stabilize the bed, and reduce the dominance of sand and fine grained bed material in these reaches. It is the presence of these finer sediments on the bed that may be partly responsible for changing occurrence and population distributions of mussel fauna in the Buttahatchee River (Jones, 1991). Since the late 1970's, the occurrence of mussel species preferring unstable substrates has increased, whereas the occurrence of those preferring stable substrates has decreased (Jones, 1991). A change to the input of sediment in the upper part of the Buttahatchee River watershed could decrease aggradation in the upper reaches, and reduce the amount of finer-grained sediment available for transport as suspended sediment or bedload. Maintenance and replanting of riparian buffer strips would be beneficial in reaches where agricultural land extends to the banks of the Buttahatchee River.

The areas of greatest instability currently occur in the lower part of the A reach and in the D reach. Figures 57 to 60 highlight these areas (rkm's A0 to A10, C84 to D90, D105 to D113 and D117 to D121) and show photos taken during RGA's and from the helicopter flight. The photos indicate that most of the problems seen along the Buttahatchee River are associated with mass wasting of the banks and associated channel widening, rather than incision.



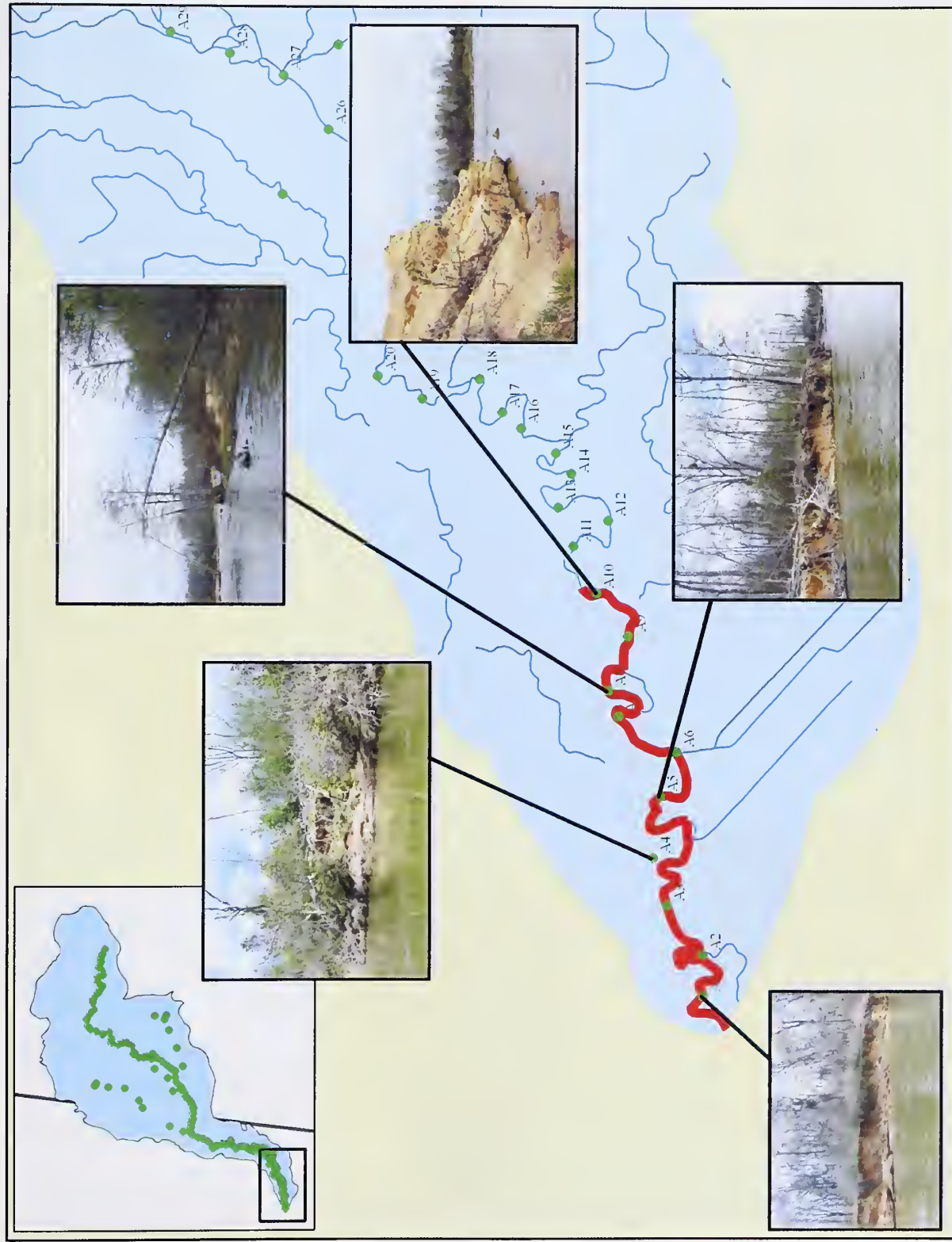


Figure 57 – Problem areas on the Buttahatchee River between rkm's A0 and A10.



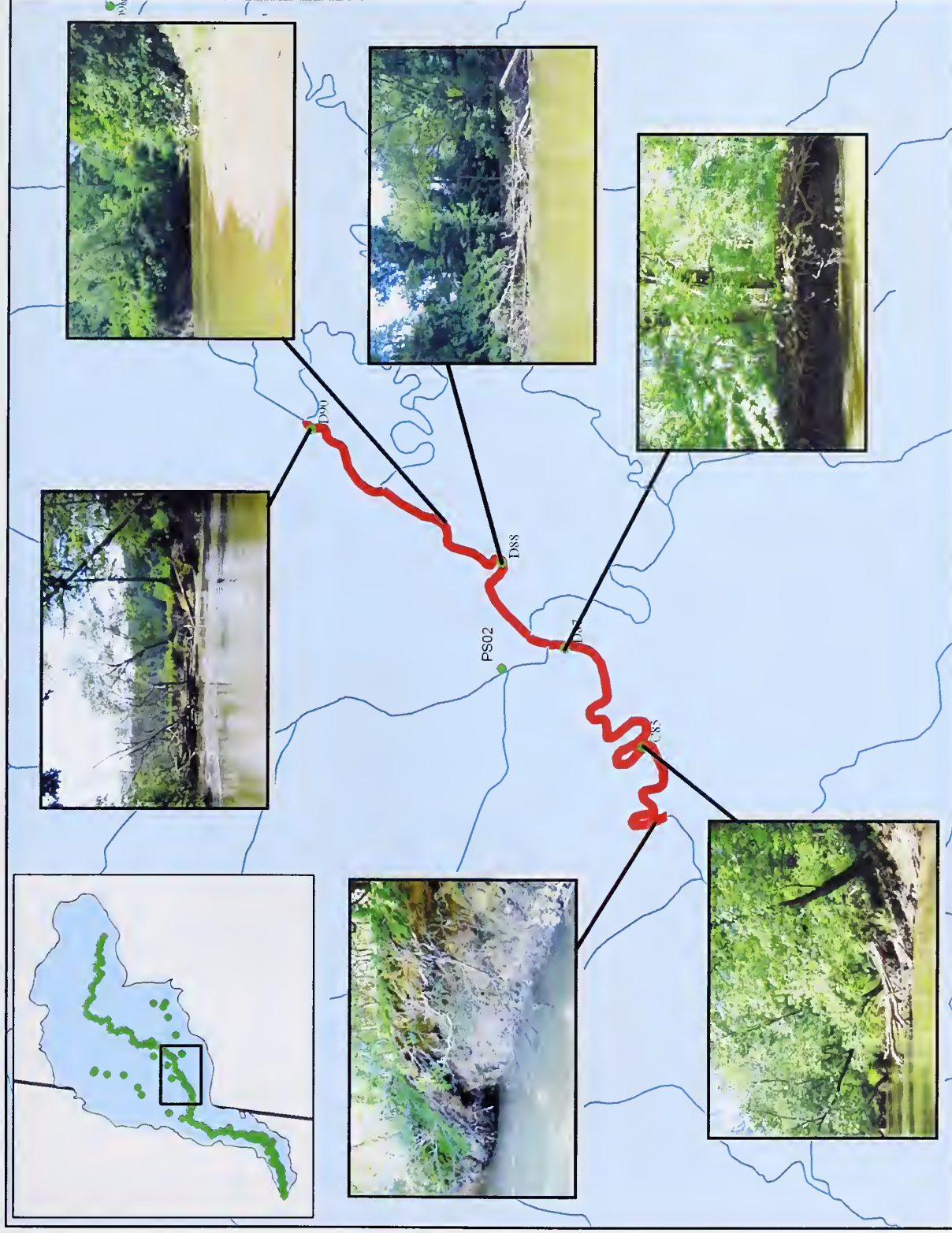


Figure 58 – Problem areas on the Buttahatchee River between rkm’s C84 and D90.



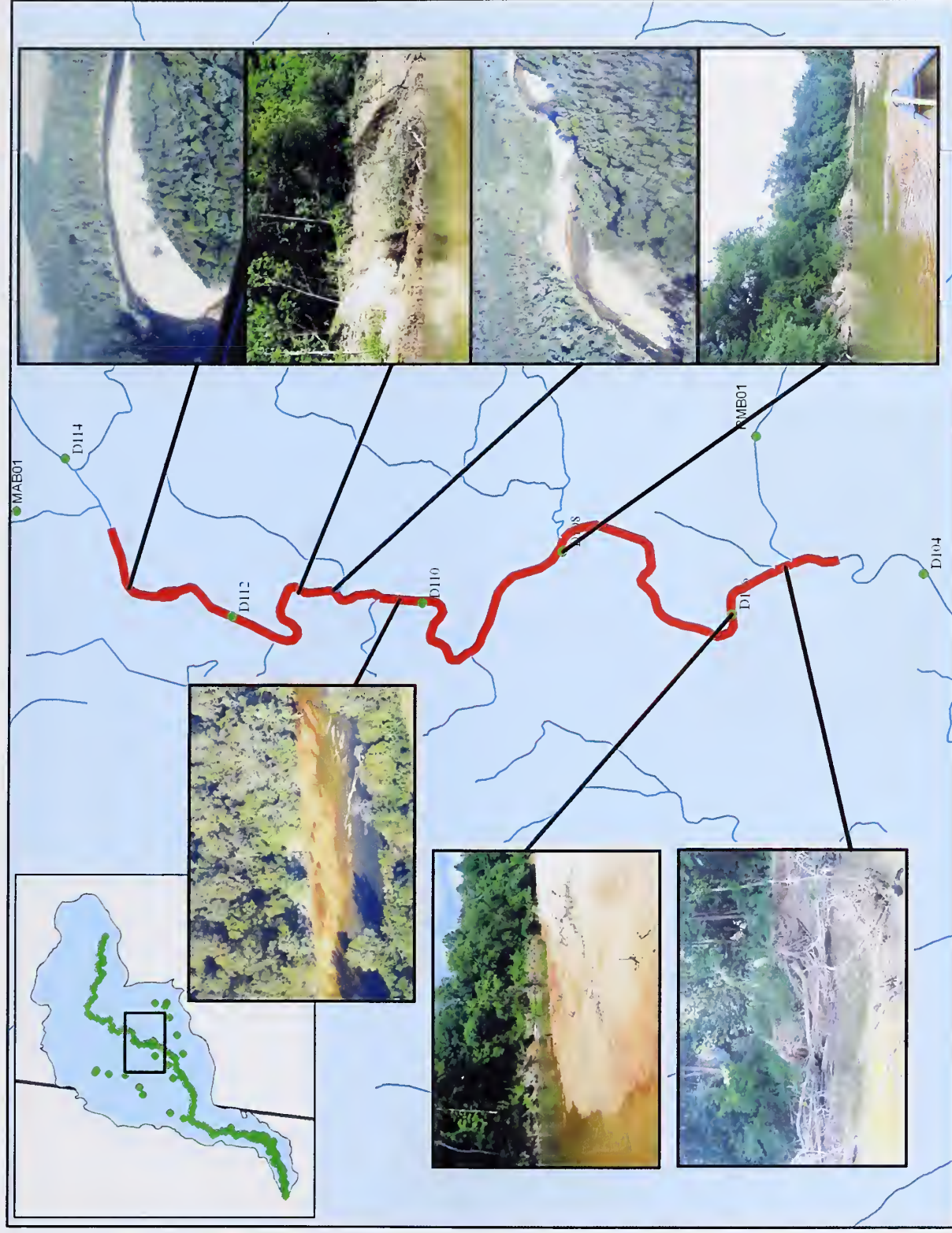


Figure 59 – Problem areas on the Buttahatchee River between rkm's D105 and D113.



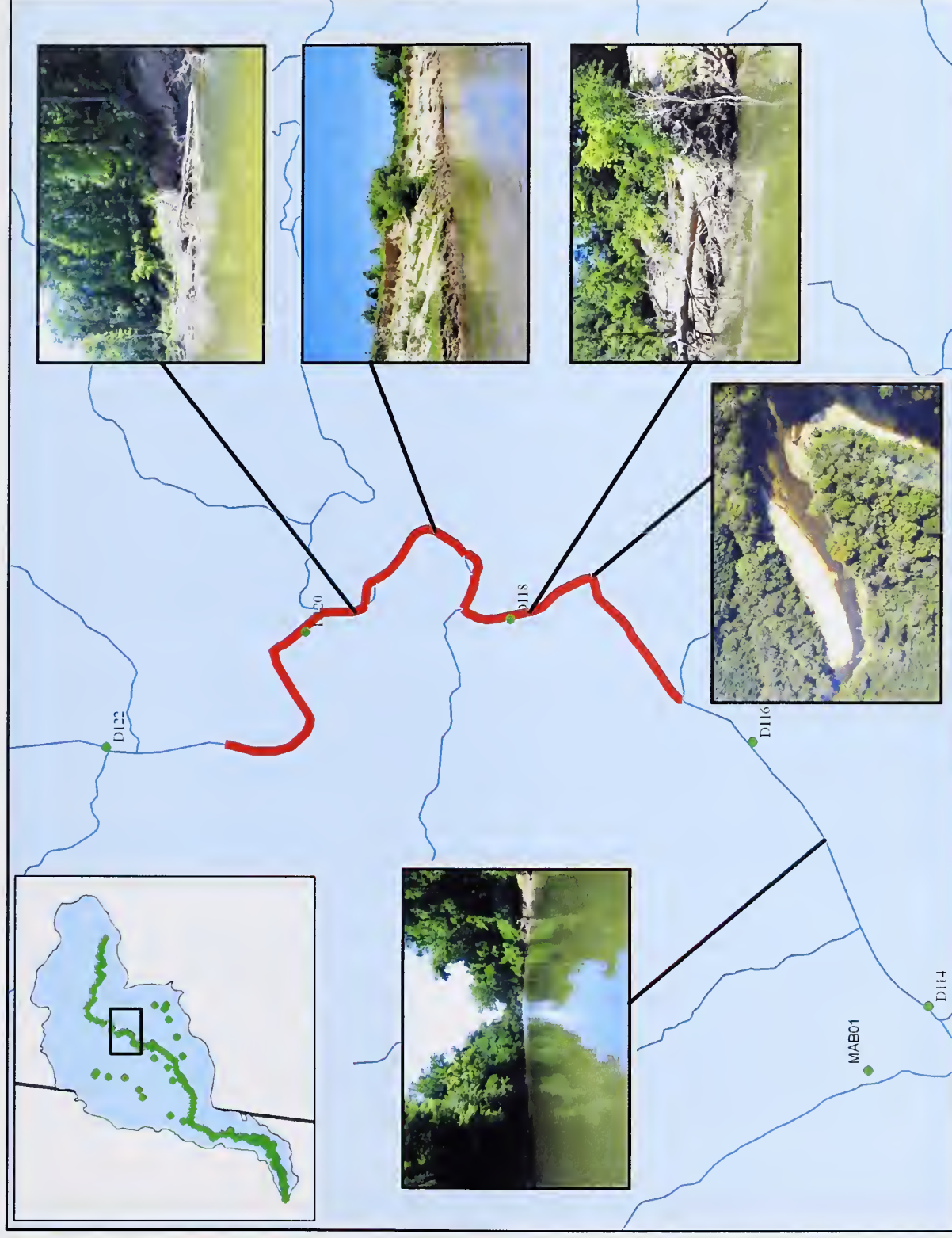


Figure 60 – Problem areas on the Buttahatchee River between rkm’s D117 and D121.



## 6. SUMMARY

The Buttahatchee River is moderately unstable throughout its length with 90 % of the sites visited along the 172 km study area unstable to at least some degree. The primary form of instability is streambank erosion and meander shifting. The general instability of the river observed during the RGAs was confirmed by helicopter reconnaissance, air photo analysis, and bank-stability modeling. Observations from the air showed that vegetation and debris from bank failures were ubiquitous along the entire length of the Buttahatchee River and that several debris jams have formed. Air-photo analysis showed that bank top-widths had increased in all reaches during all of the time periods studied, with reaches A and D being particularly unstable at present. Average rates of channel widening in each reach for each time period show the channel's response to both natural and anthropogenic disturbances that have occurred over the past 35 years. Areas of maximum bank instability occur at the lower end of reach A, where impoundment has probably increased bank saturation, caused aggradation and associated widening, and in reach D, where instability appears to be influenced to a large extent by land use, causing accretion on and associated accelerated erosion on the outside of meander bends. Analysis of gage data show how preferential deposition on bars and on inside bends results in an increase in hydraulic depth, greater average boundary shear stress for a given discharge, and enhanced ability to transport sediment generated from upstream. Still, most of the Buttahatchee River is experiencing aggradation (stage V), indicating that it still does not have sufficient flow energy to transport all of the sediment in the system.

The channel is responding to a number of disturbances that have predominantly occurred in reach A, and have propagated upstream, and to other disturbances that are affecting reach D and are propagating downstream. The disturbances to reach A include "natural" and anthropogenic meander cutoffs, construction of the Tennessee-Tombigbee Waterway including impoundment of the Columbus pool, and gravel-mine capture and ponding. Disturbances in reach D are related to the delivery of excessive amounts of sediment to the reach due to land-use practices and the consequent streambank instability associated with bar growth and flow deflection.

Extensive lengths of channel in reaches A and B are dominated by gravel beds even though the impoundment of the TTW has increased aggradation near the mouth of the Buttahatchee River due to a raising of base level. Aggradation is also seen in reaches A and B on channel bars although the bed of the thalweg is still predominantly gravel. Reaches A through C are also effected by the gravel-mine capture that increased water-surface slope because the water at the mines is now spread over a wider area, thus reducing flow depth and increasing the water-surface slope towards the mines.

In reaches C and D there seems to be an energy imbalance in the system, with more sand being introduced into the system than can be transported. Aggradation and deposition of sand on the bed and on bars is thus occurring, partly as a result of land-use issues in the upper reaches of the Buttahatchee River watershed. Air-photo analysis and notes taken



during aerial reconnaissance suggest that edge-of-field gullies on the Buttahatchee River are not a significant source of sediment. An important result from the air-photo analysis was that the channel length increased slightly in the last period of air-photo analysis (1992-1999). The increase in length is accomplished by extension and elongation (erosion) of the outsides of meander bends, as flow is deflected away from accreting bars. The bank erosion then provides a continued source of sand-sized sediment to accreting bars causing further flow deflection to the opposite bank and hence, continued meander movement.

The instability seen in the Buttahatchee River therefore seems to be a result of disturbances that have occurred in two different reaches. Most of the channel modifications have affected reach A (TTW construction, meander cutoffs, gravel mine capture) and the effects of these disturbances can now be seen to have migrated upstream as far as reach C. In reach D significant instability also exists in certain parts of the reach, and this appears to be a result of an imbalance between sediment delivery and flow energy in the channel. Logging and increased agricultural land use in the proximity of the channel over the period of study, have led to considerable delivery of sediment to the channel in this reach. As a result, a positive feedback loop has developed, involving bar accretion and associated erosion of outer meander bends. The effect of disturbances in the Buttahatchee River are thus working their way both upstream and downstream from the sites of original disturbance, creating a complex pattern of response. The causes and direction of responses to these disturbances are summarized in Figure 61. As can be seen in Figure 61, the responses to disturbances in reaches A and D are moving in opposite directions and therefore have complex effects on the channel's response and search for a new quasi-equilibrium condition.



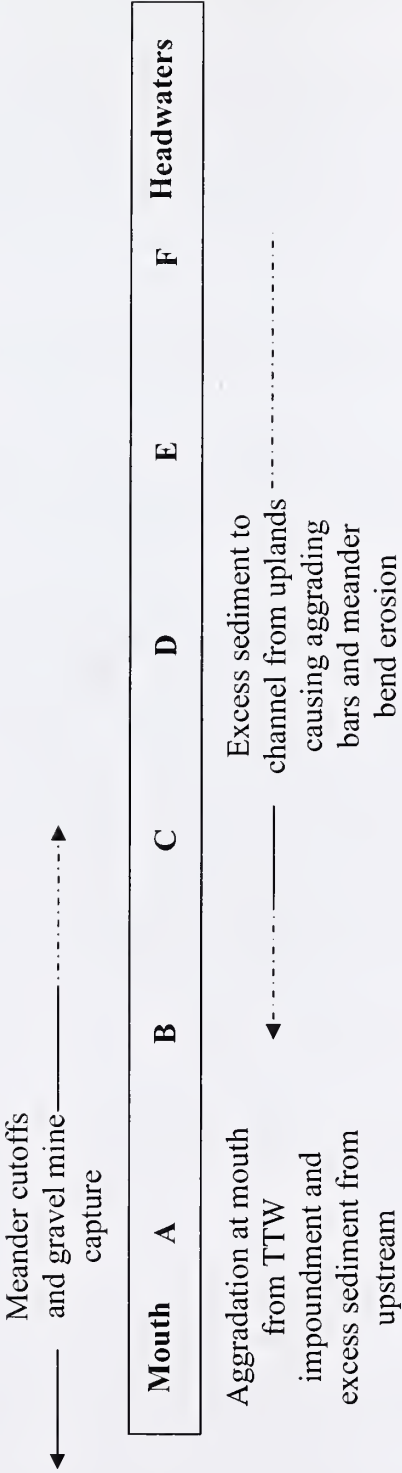
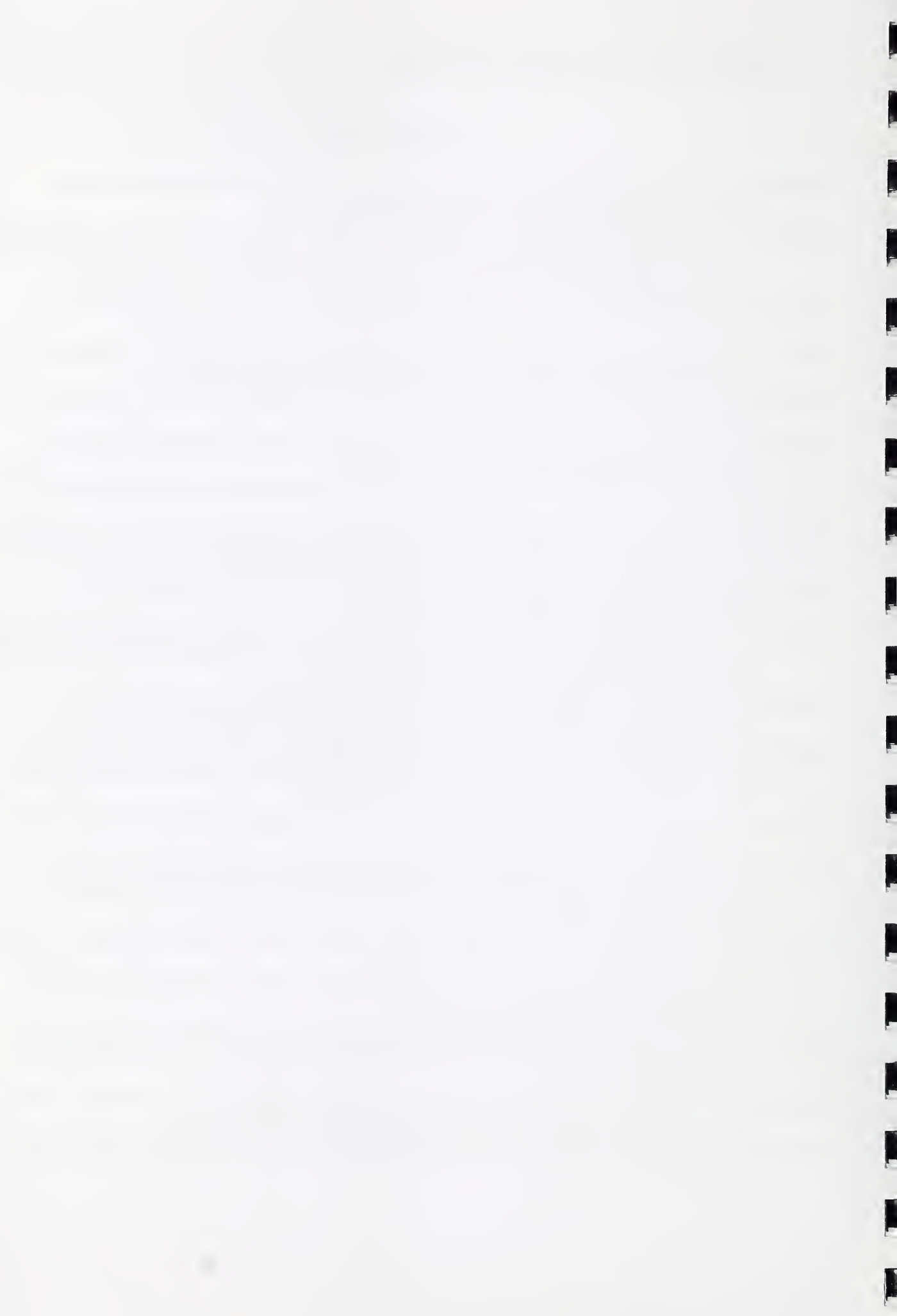


Figure 61 - Summary of disturbance locations and the direction and extent of the responses to these disturbances.



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## **APPENDICES**

**APPENDIX A – Bank stratigraphy, geotechnical data and channel cross-sections for intensive sites.**

**APPENDIX B – Particle-size values of bank material at intensive sites; A10, A28, B42, C71, D88, E129, E157.5**

**APPENDIX C – Particle-size values for bed material along the Buttahatchee River.**

**APPENDIX D – Rapid Geomorphic Assessment (RGA) data from the Buttahatchee River main stem and several tributaries.**

**APPENDIX E – Locations of Rapid Geomorphic Assessments (RGAs) carried out on the Buttahatchee River and select Tributaries.**

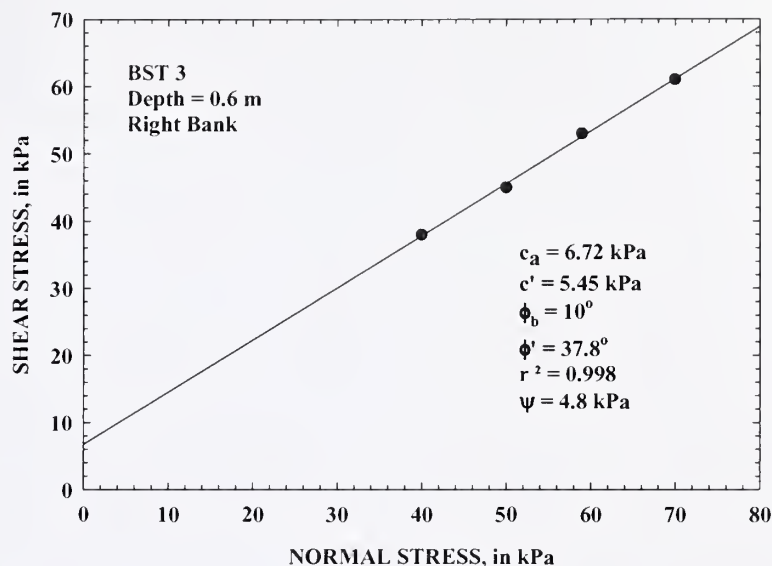
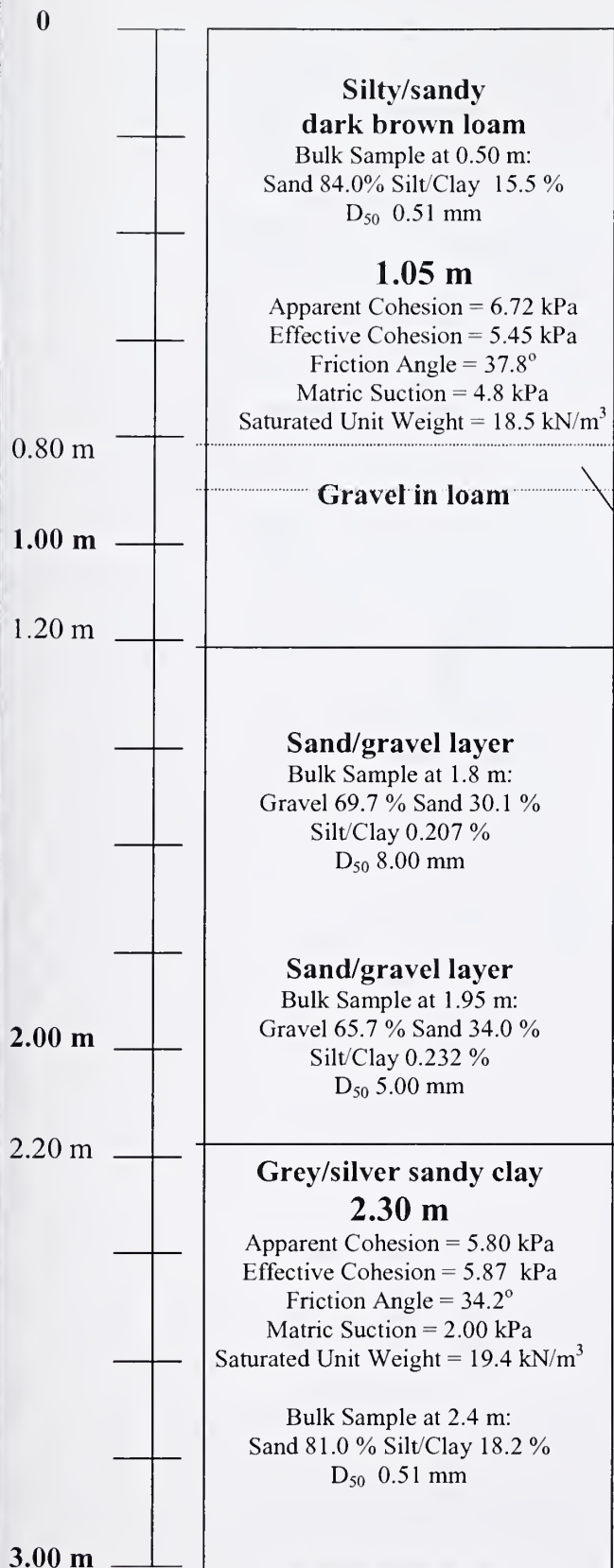


## **APPENDIX A**

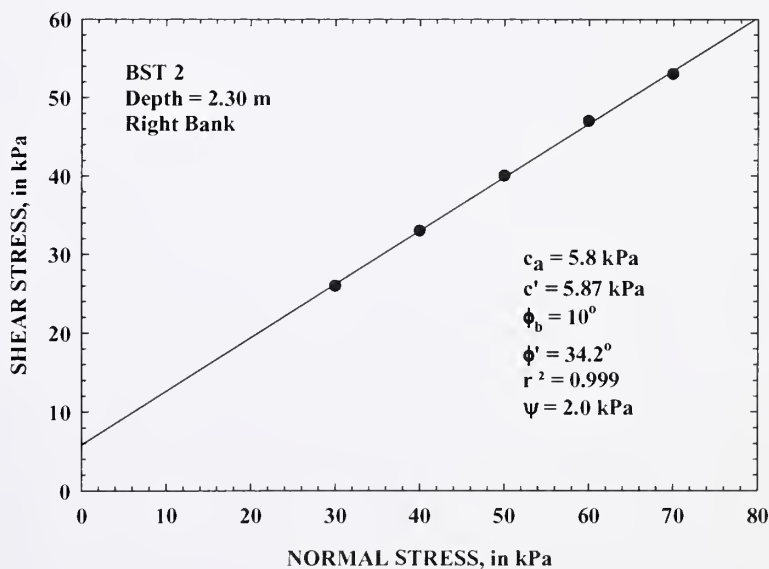
**Bank stratigraphy, geotechnical data and channel cross-sections  
for intensive sites.**



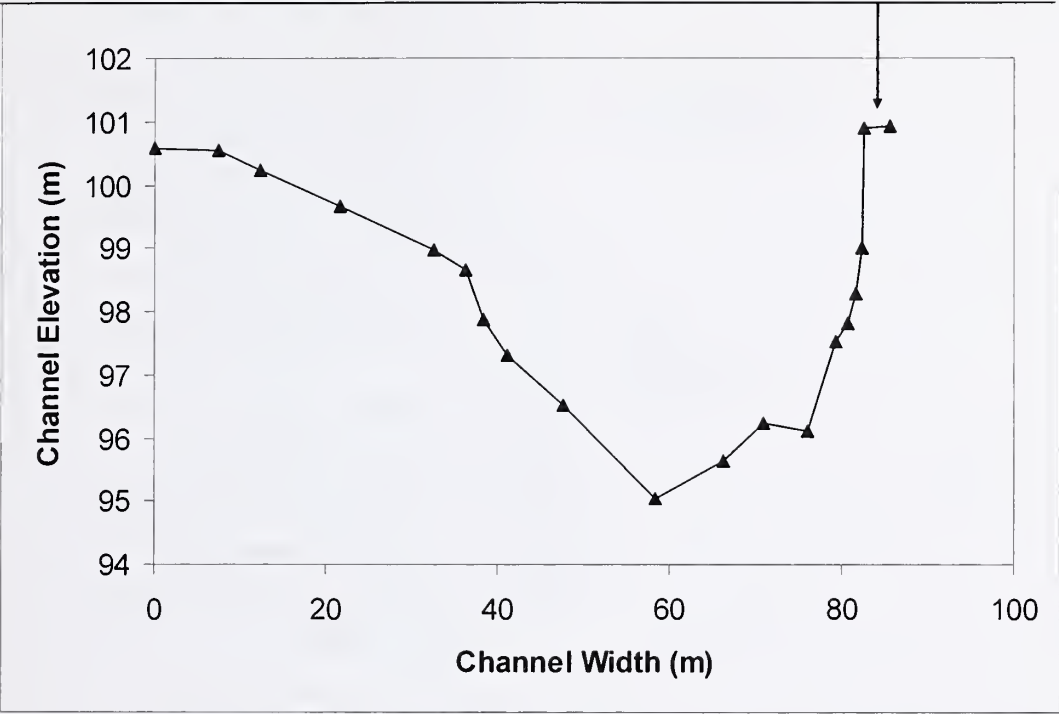
## A10 Left Bank



Bulk Sample at 0.8 m:  
Gravel 70.0 % Sand 28.3 %  
Silt and Clay 1.71 %  
 $D_{50}$  4.2 mm

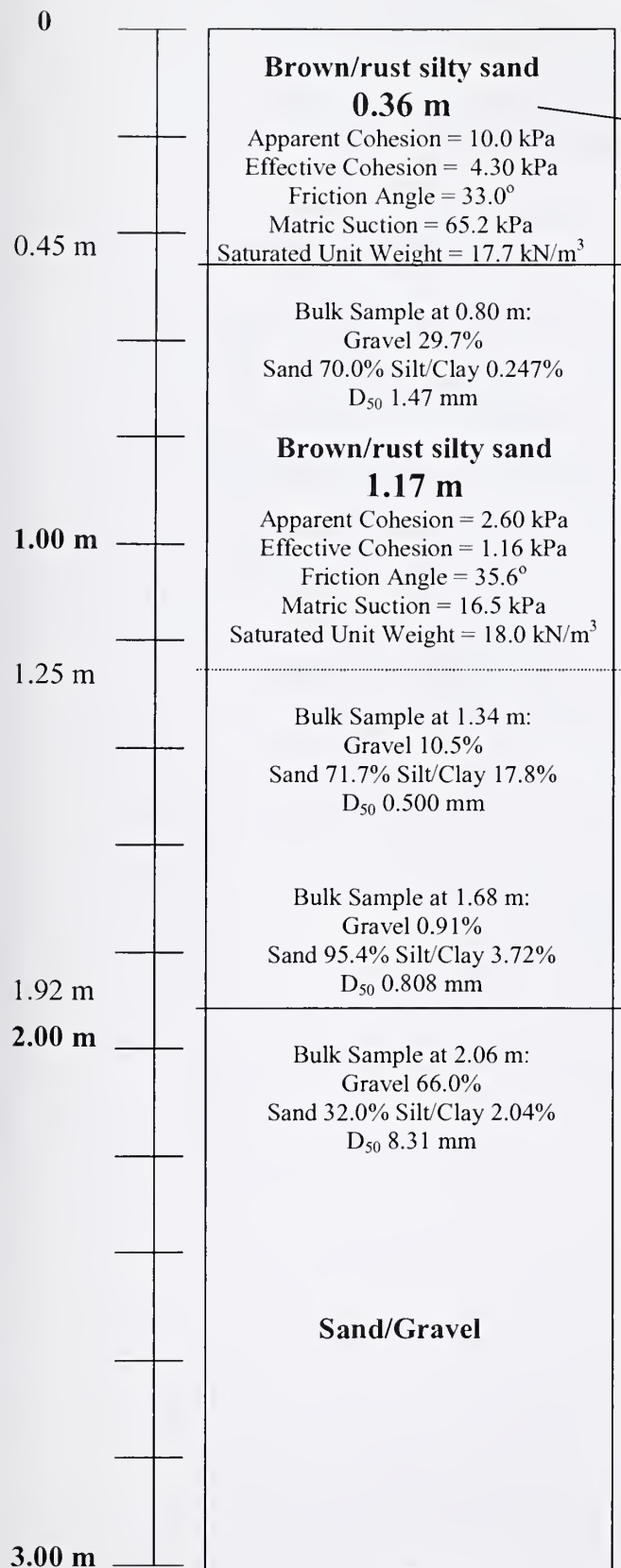




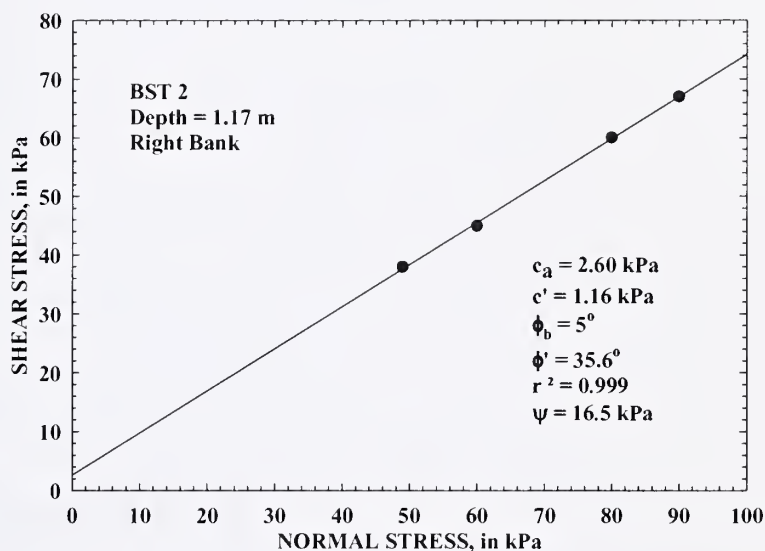




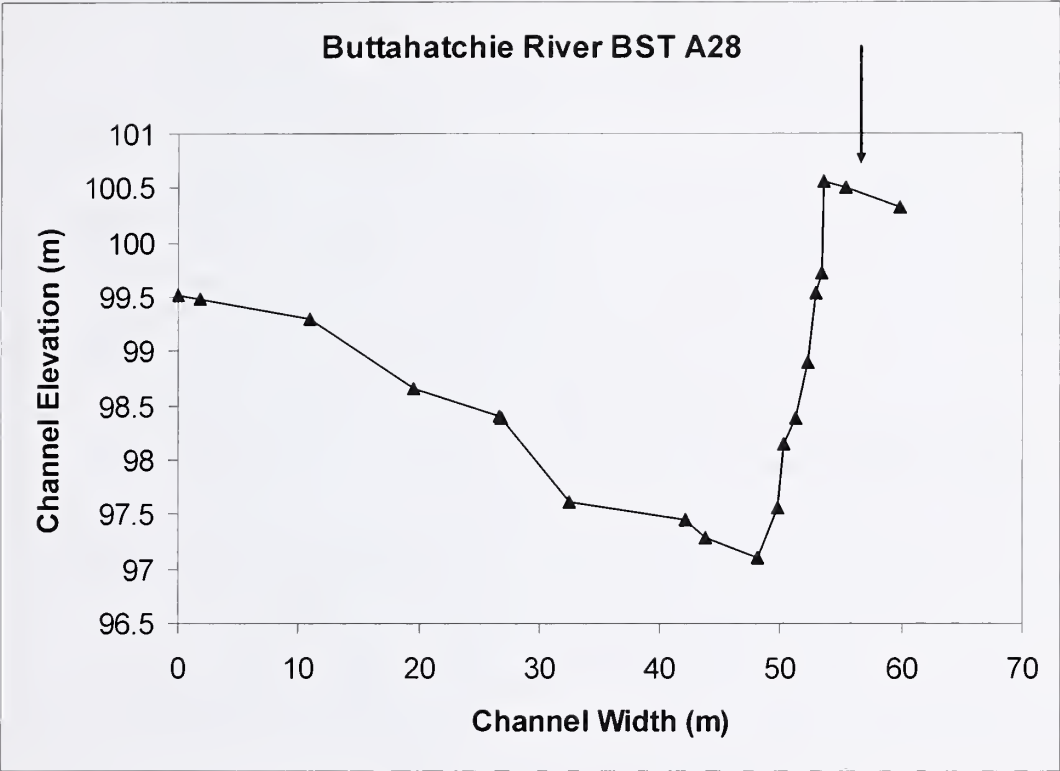
## A28 Right Bank



Bulk Sample at 0.27 m:  
 Sand 92.6% Silt/Clay 7.41%  
 D<sub>50</sub> 0.810 mm

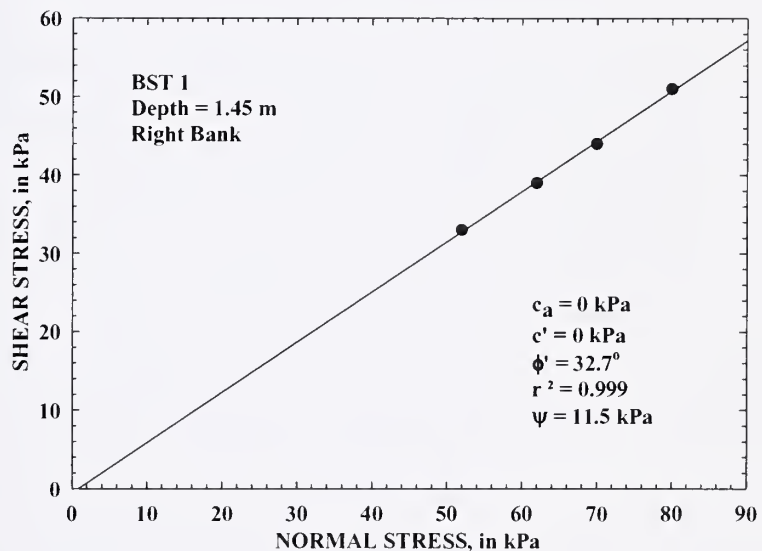
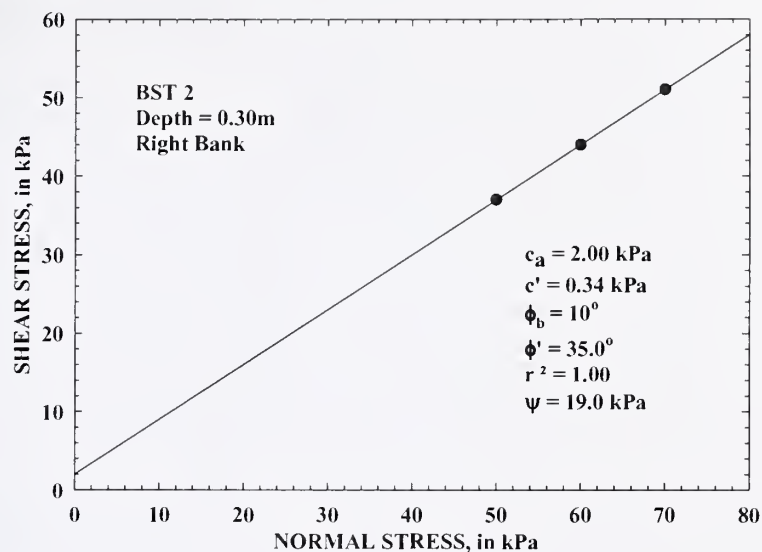
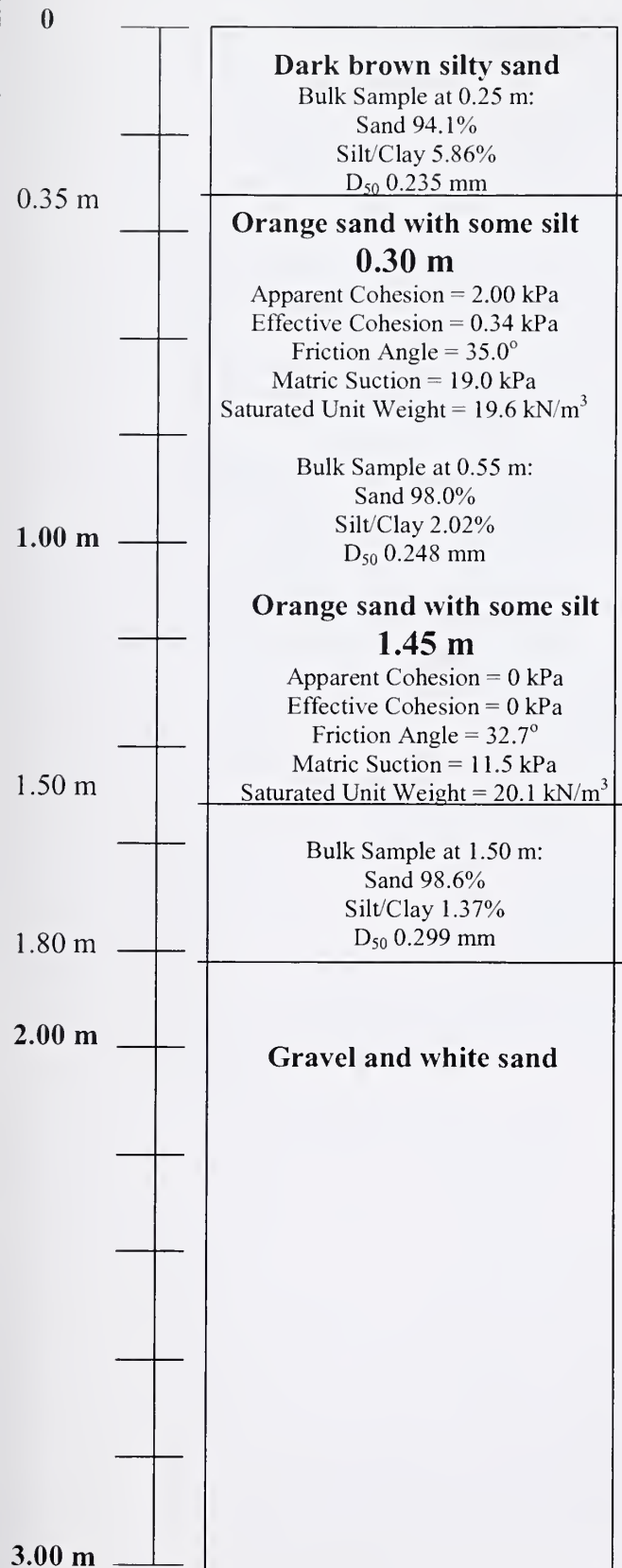




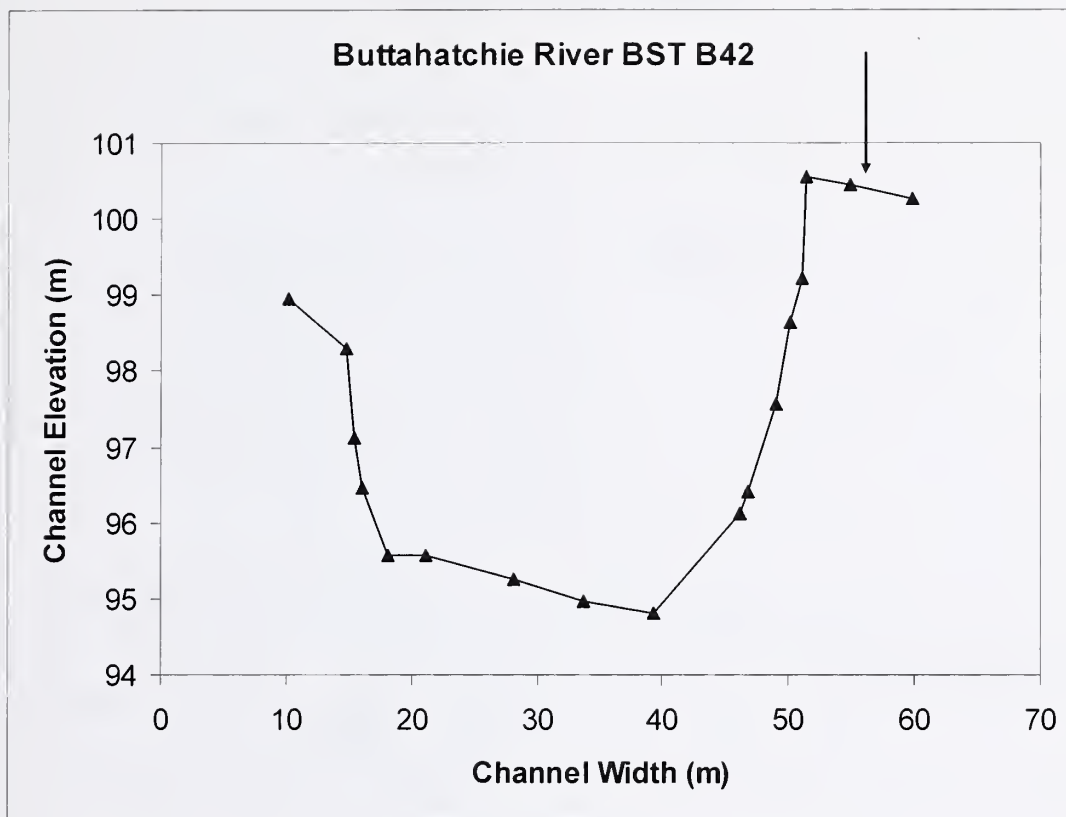




# B42 Right Bank

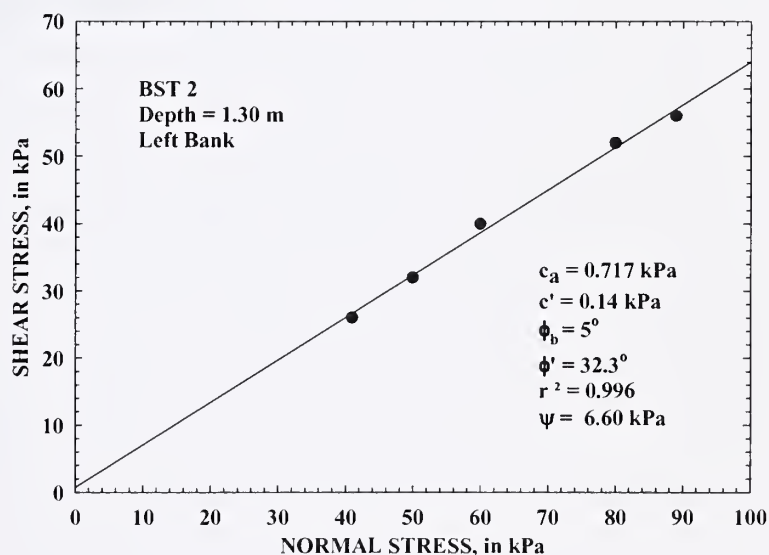
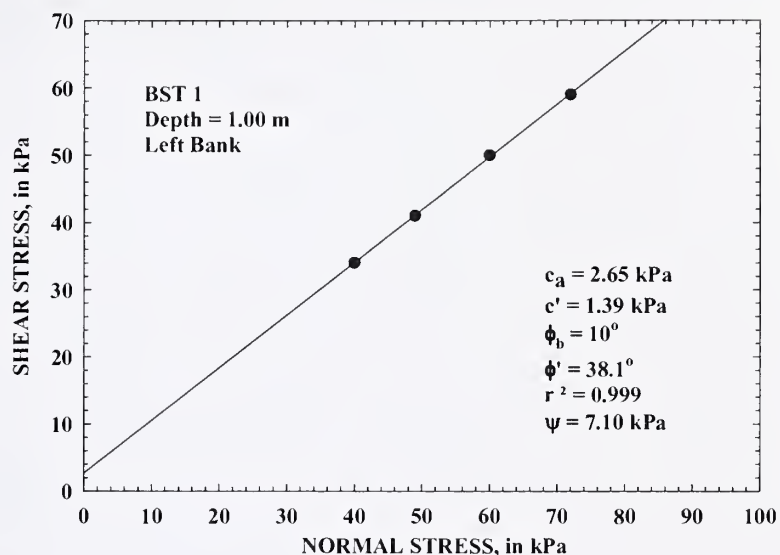
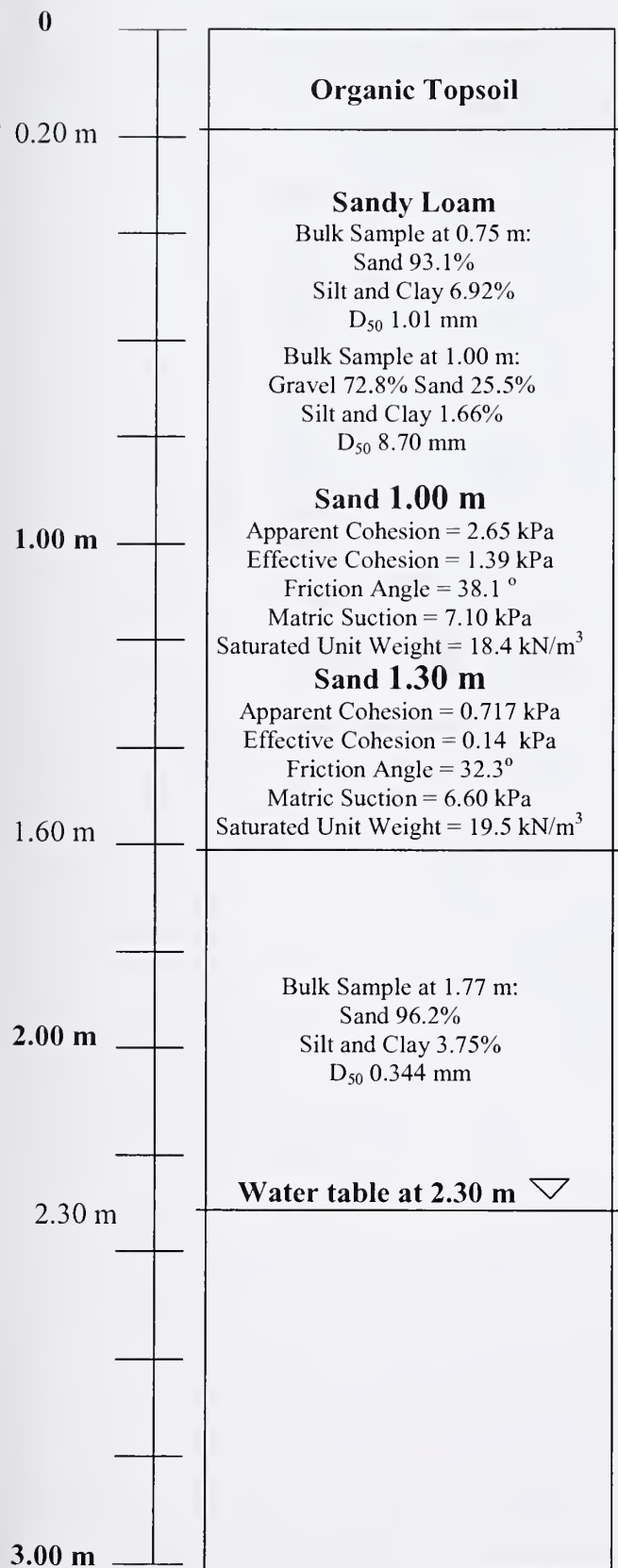




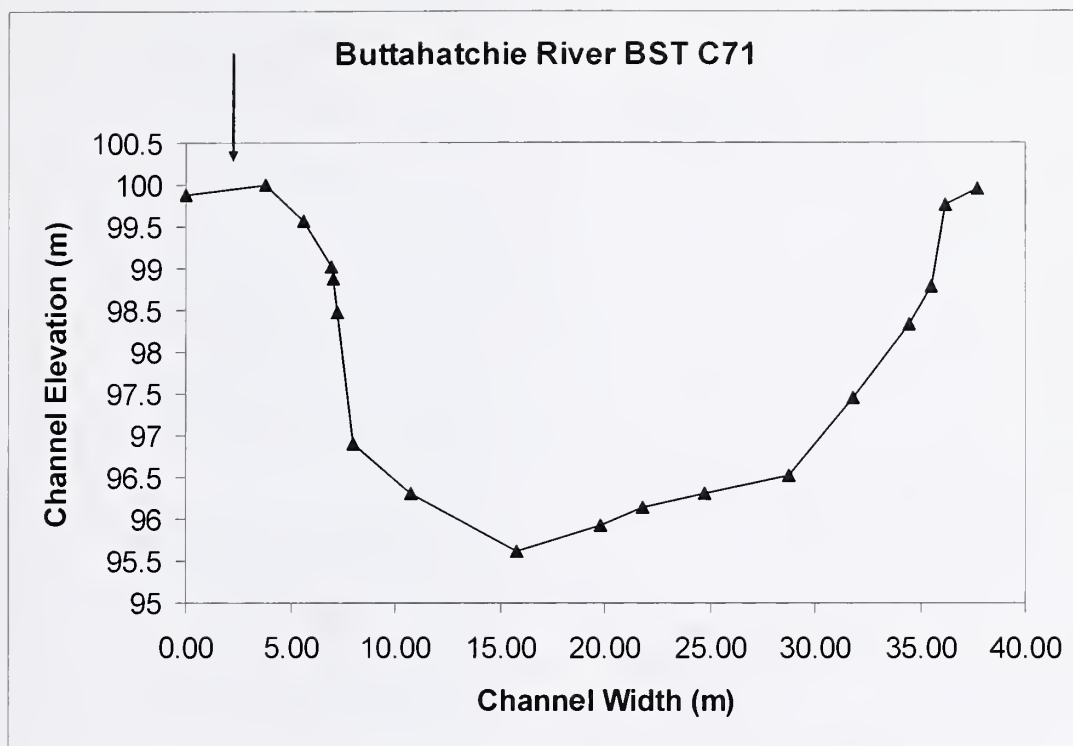




## C71 Left Bank

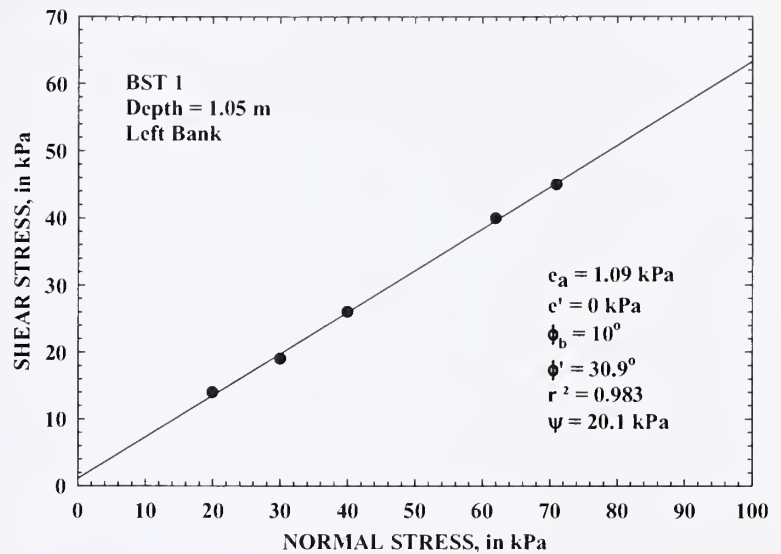
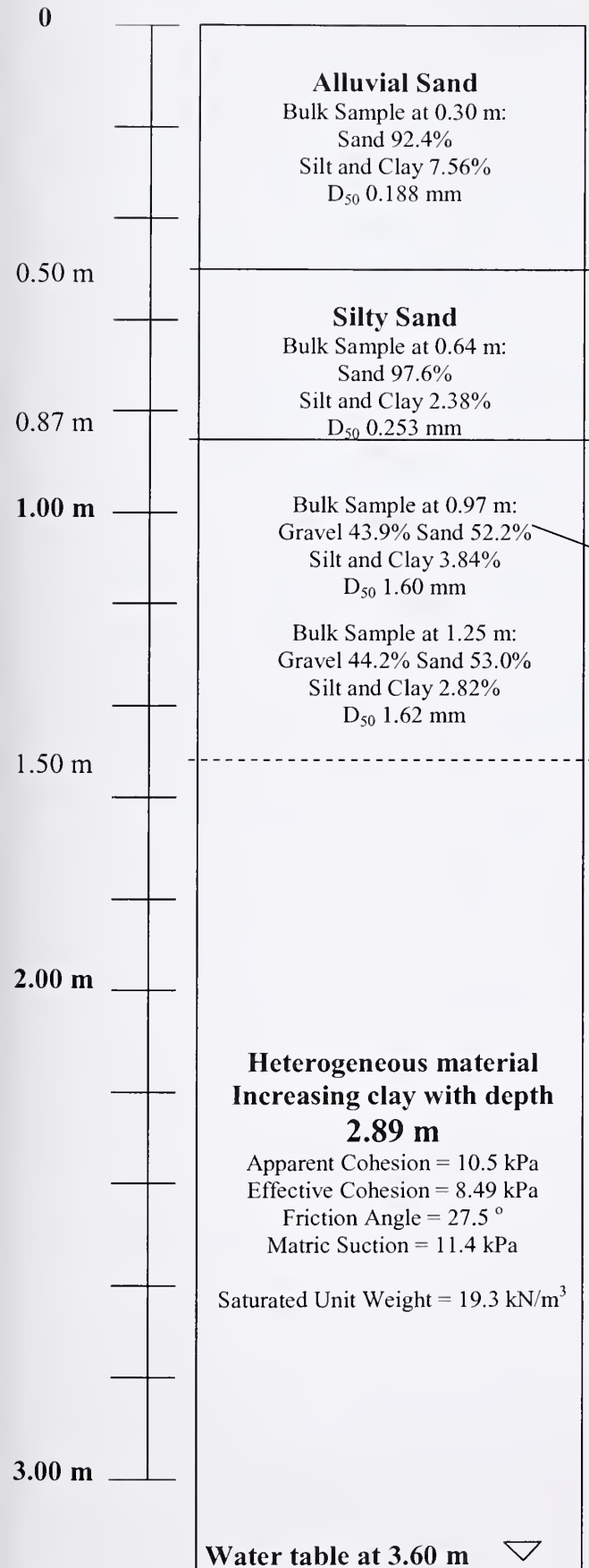








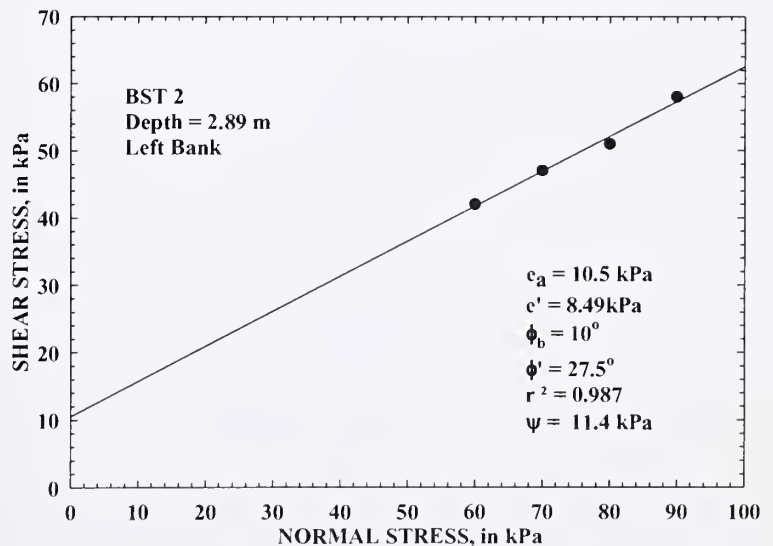
## D88 Left Bank



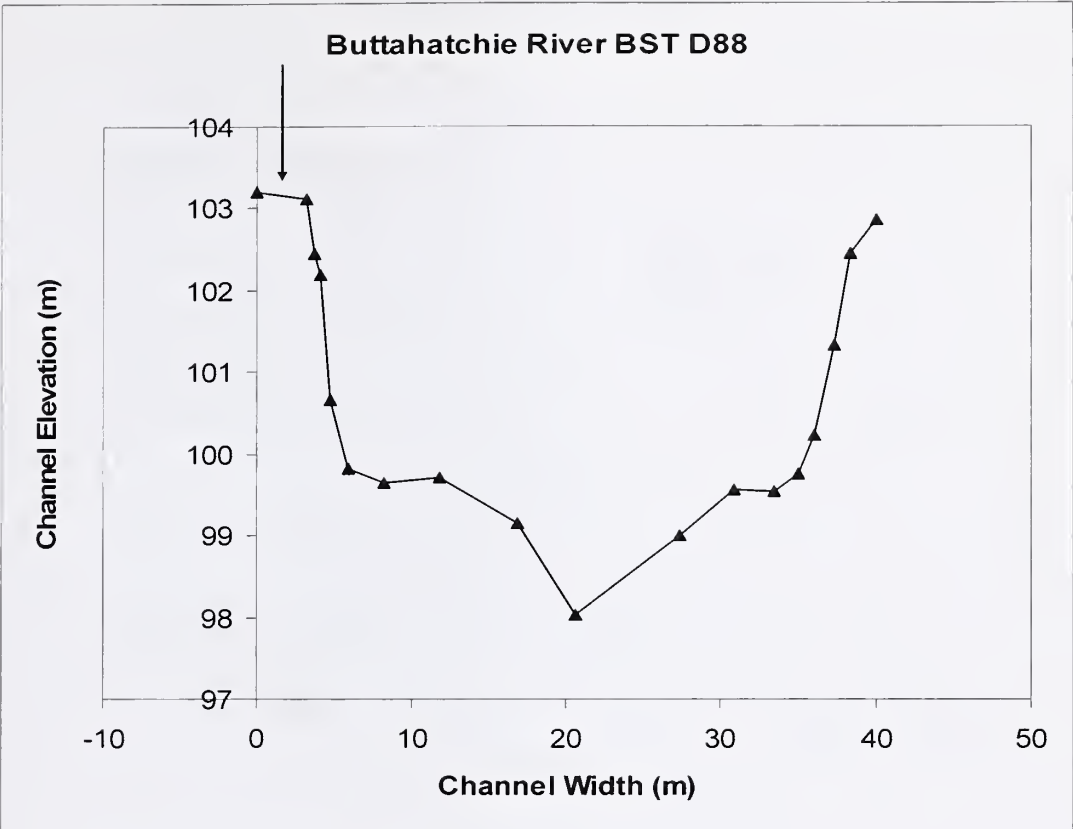
**Brown heterogeneous**  
**Sandy gravel**  
**1.05 m**

Apparent Cohesion = 1.09 kPa  
Effective Cohesion = 0 kPa  
Friction Angle =  $31.8^\circ$   
Matric Suction = 18.9 kPa

Saturated Unit Weight =  $18.1 \text{ kN/m}^3$

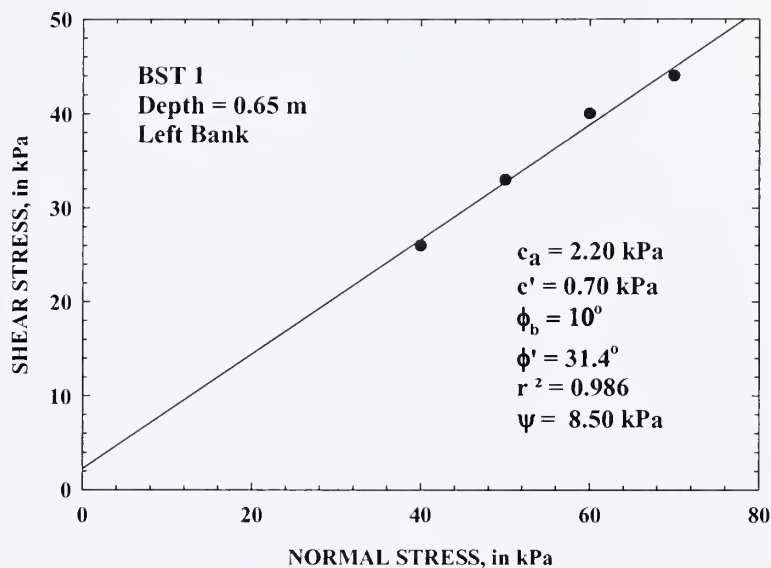
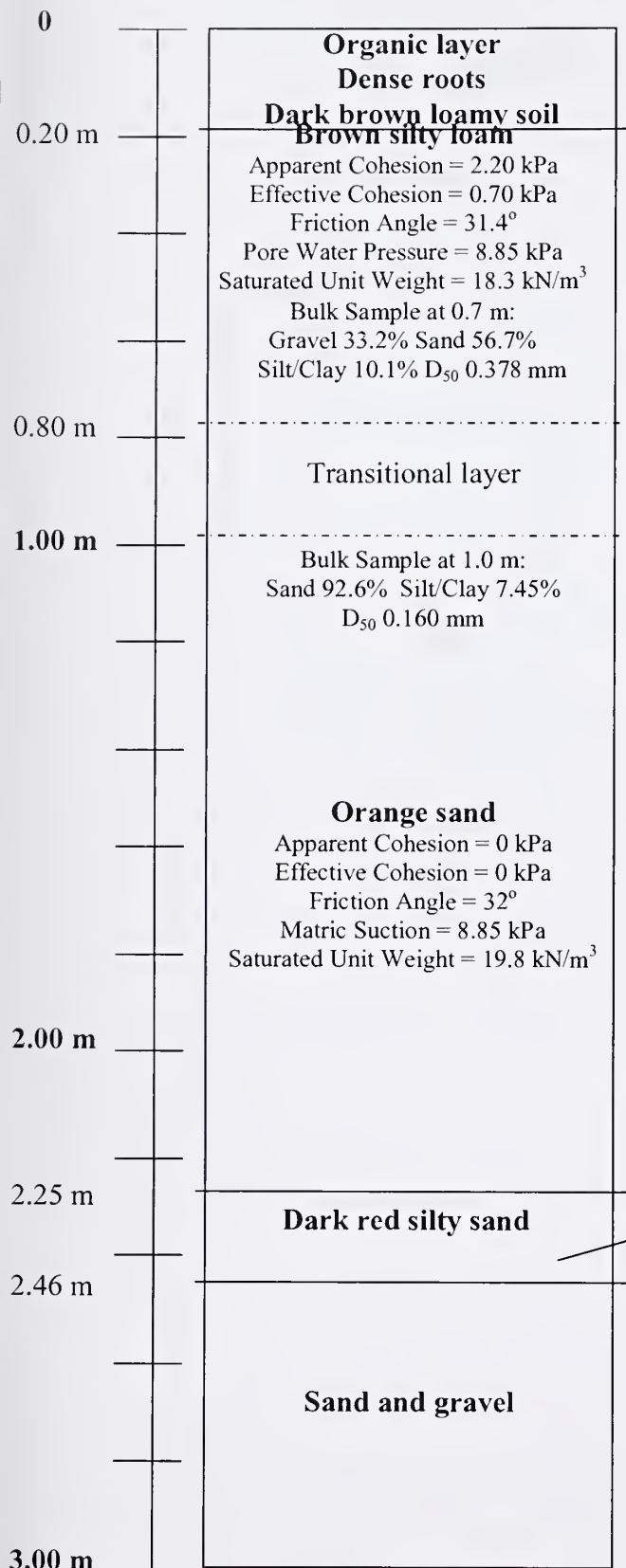






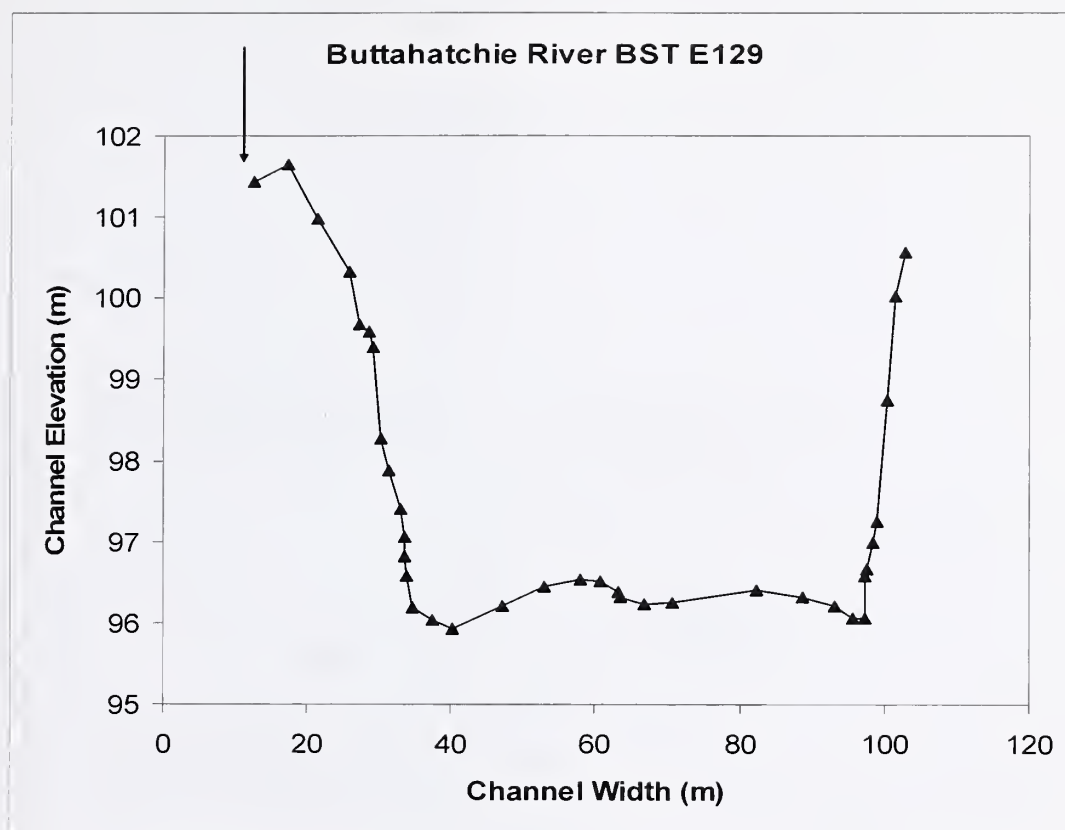


## E129 Left Bank



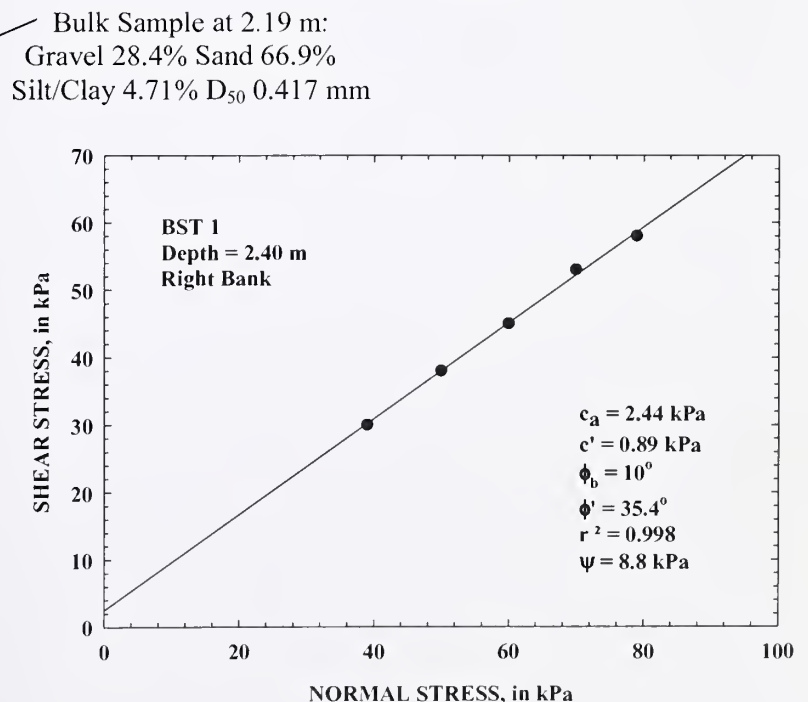
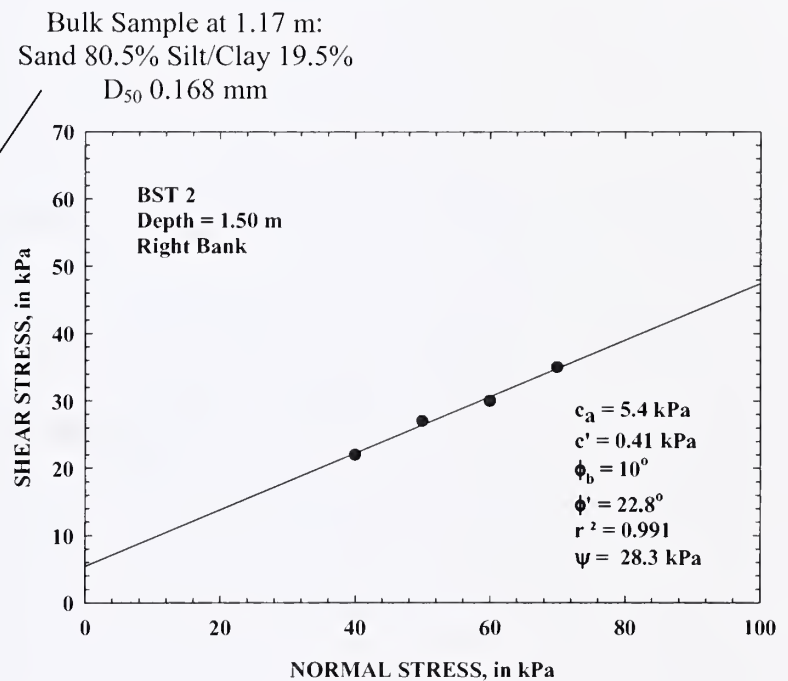
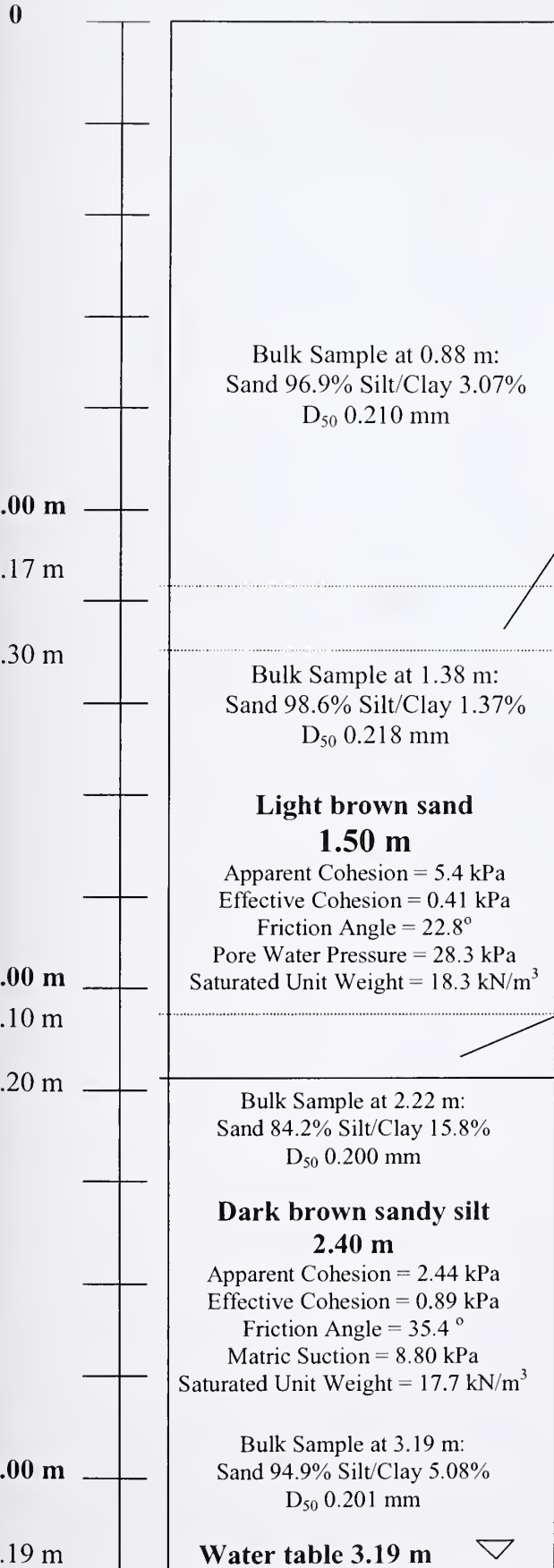
Bulk Sample at 2.25 m:  
 Gravel 31.1% Sand 67.0%  
 Silt/Clay 1.83%  $D_{50}$  0.530 mm



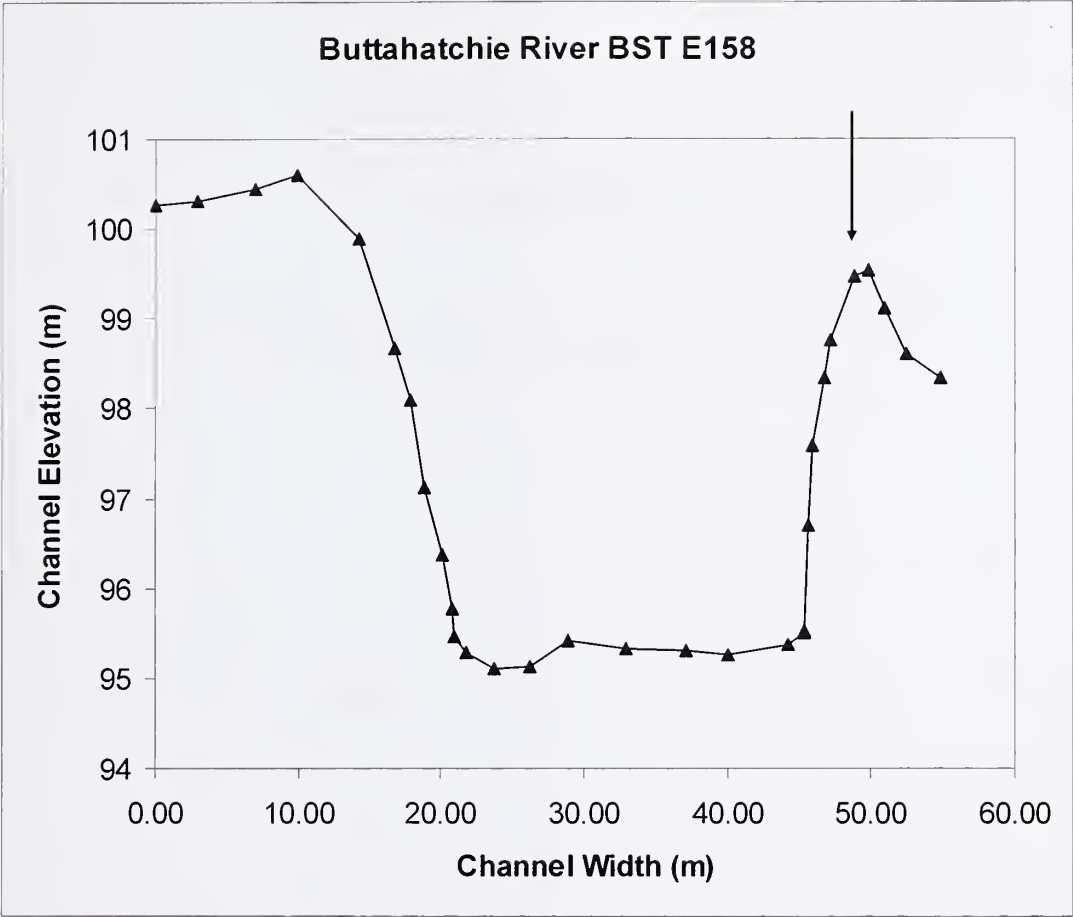




# E157.5 Right Bank









**APPENDIX B**

**Particle-size values of bank material at intensive sites;  
A10, A28, B42, C71, D88, E129, E157.**



### Appendix B – Bank material particle-size values at intensive sites along the Buttahatchee River.

Site	Sample location	Percentage				D <sub>50</sub> * in millimeters
		Bedrock/ Boulders/ Cobbles > 64.0 mm	Gravel 2.00 - 64.0 mm	Sand 0.063 - 1.99 mm	Silt and clay < 0.063 mm	
A10	RB 0.5 m	0.00	0.48	84.0	15.5	0.51
A10	RB 0.8 m	0.00	70.0	28.3	1.71	4.2
A10	RB 1.8 m	0.00	69.7	30.1	0.207	8
A10	RB 1.95 m	0.00	65.7	34.0	0.232	5
A10	RB 2.4 m	0.00	0.00	81.8	18.2	0.51
A38	RBtoe	0.00	5.28	91.2	3.53	0.308
A38	RB 0.27 m	0.00	0.00	92.6	7.41	0.81
A38	RB 0.80 m	0.00	29.7	70.0	0.247	1.47
A38	RB 1.34 m	0.00	10.5	71.7	17.8	0.5
A38	RB 1.68 m	0.00	0.906	95.4	3.72	0.808
A38	RB 2.06 m	0.00	66.0	32.0	2.04	8.31
B42	RBtoe	0.00	59.8	39.3	0.951	5.09
B42	RB 0.25 m	0.00	0.00	94.1	5.86	0.235
B42	RB 0.55 m	0.00	0.00	98.0	2.02	0.248
B42	RB 1.50 m	0.00	0.00	98.6	1.37	0.299
C71	LBTtoe	0.00	22.8	62.7	14.5	1.01
C71	LB 0.75 m	0.00	0.00	93.1	6.92	1.01
C71	LB 1.0 m	0.00	72.8	25.5	1.66	8.7
C71	LB 1.77 m	0.00	0.00	96.2	3.75	0.344
D88	LBTtoe	100	0.00	0.00	0.00	5000
D88	LB 0.3 m	0.00	0.00	92.4	7.56	0.188
D88	LB 0.64 m	0.00	0.00	97.6	2.38	0.253
D88	LB 0.97 m	0.00	43.9	52.2	3.84	1.6
D88	LB 1.25 m	0.00	44.2	53.0	2.82	1.62
E129	LBTtoe	100	0.00	0.00	0.00	5000
E129	LB 0.7 m	0.00	33.2	56.7	10.1	0.378
E129	LB 1.0 m	0.00	0.00	92.6	7.45	0.16
E129	LB 2.25 m	0.00	31.1	67.0	1.83	0.53
E157.5	RBTtoe	100	0.00	0.00	0.00	5000
E157.5	RB 0.88 m	0.00	0.00	96.9	3.07	0.21
E157.5	RB 1.17 m	0.00	0.00	80.5	19.5	0.168
E157.5	RB 1.38 m	0.00	0.00	98.6	1.37	0.218
E157.5	RB 2.19 m	0.00	28.4	66.9	4.71	0.417
E157.5	RB 2.22 m	0.00	0.00	84.2	15.8	0.2
E157.5	RB 3.19 m	0.00	0.00	94.9	5.08	0.201

\* Where no sample was taken the following D<sub>50</sub> value was used.  
Bedrock; 5000 mm



## **APPENDIX C**

### **Particle-size values for bed material along the Buttahatchee River**



**Appendix C – Bed material particle-size values along the Buttahatchee River.**

Site	Sample taken	Percentage				D <sub>50</sub> in millimeters*
		Bedrock/Hard Clay/Cemented Sands/Boulders/Cobbles > 64.0 mm	Gravel 2.00 - 64.0 mm	Sand 0.063 - 1.99 mm	Silt and clay < 0.063 mm	
A1	-	0.00	100	0.00	0.00	11.3
A2	-	0.00	100	0.00	0.00	11.3
A3	-	0.00	100	0.00	0.00	11.3
A4	-	0.00	100	0.00	0.00	11.3
A5	-	0.00	100	0.00	0.00	11.3
A6	-	0.00	100	0.00	0.00	11.3
A7	-	0.00	100	0.00	0.00	11.3
A8	-	0.00	100	0.00	0.00	11.3
A9	-	0.00	100	0.00	0.00	11.3
A10	-	0.00	100	0.00	0.00	11.3
A11	-	0.00	100	0.00	0.00	11.3
A12	-	0.00	100	0.00	0.00	11.3
A13	-	0.00	100	0.00	0.00	11.3
A14	-	0.00	100	0.00	0.00	11.3
A15	-	0.00	100	0.00	0.00	11.3
A16	-	0.00	100	0.00	0.00	11.3
A17	-	0.00	100	0.00	0.00	11.3
A18	-	0.00	100	0.00	0.00	11.3
A19	-	0.00	100	0.00	0.00	11.3
A20	-	0.00	100	0.00	0.00	11.3
A21	-	0.00	100	0.00	0.00	11.3
A22	-	0.00	100	0.00	0.00	11.3
A23	-	0.00	100	0.00	0.00	11.3
A24	-	0.00	100	0.00	0.00	11.3
A25	-	0.00	100	0.00	0.00	11.3
A26	-	0.00	100	0.00	0.00	11.3
A27	-	0.00	100	0.00	0.00	11.3
A28	-	0.00	100	0.00	0.00	11.3
A29	-	0.00	100	0.00	0.00	11.3
A30	-	0.00	100	0.00	0.00	11.3
A31	-	0.00	100	0.00	0.00	11.3
A32	-	0.00	100	0.00	0.00	11.3
A33	-	0.00	100	0.00	0.00	11.3
A34	-	0.00	100	0.00	0.00	11.3
A35	-	0.00	100	0.00	0.00	11.3
A36	-	0.00	100	0.00	0.00	11.3
A37	-	0.00	100	0.00	0.00	11.3
A38	-	0.00	100	0.00	0.00	11.3
A39	-	0.00	100	0.00	0.00	11.3
A40	-	0.00	100	0.00	0.00	11.3



Site	Sample taken	Percentage				D <sub>50</sub> in millimeters*
		Bedrock/Hard Clay/Cemented Sands/Boulders/Cobbles > 64.0 mm	Gravel 2.00 - 64.0 mm	Sand 0.063 - 1.99 mm	Silt and clay < 0.063 mm	
A41	-	0.00	100	0.00	0.00	11.3
A42	-	0.00	100	0.00	0.00	11.3
B44	-	0.00	100	0.00	0.00	11.3
B46	-	0.00	100	0.00	0.00	11.3
B48	-	0.00	100	0.00	0.00	11.3
B50	-	0.00	100	0.00	0.00	11.3
B52	-	0.00	100	0.00	0.00	11.3
B54	-	0.00	100	0.00	0.00	11.3
B56	-	0.00	100	0.00	0.00	11.3
B58	-	0.00	50.0	50.0	0.00	5.83
C60	-	0.00	0.00	100	0.00	0.355
C63	-	0.00	100	0.00	0.00	11.3
C65	-	0.00	100	0.00	0.00	11.3
C67	-	0.00	100	0.00	0.00	11.3
C69	Sample	0.00	0.00	100	0.00	0.3
C71	Sample	0.00	30.8	68.7	0.474	0.4
C73	Sample	0.00	0.00	100	0.00	0.301
C75	Sample	0.00	0.362	99.0	0.676	0.312
C77	Sample	0.00	29.5	69.6	0.956	0.26
C79	Sample	0.00	0.274	96.3	3.44	0.175
C81	-	20.0% Hard Clay	0.00	80.0	0.00	-
C83	Sample	0.00	0.00	100	0.00	0.28
C85	Sample	0.00	0.00	100	0.00	0.33
D87	Sample	0.00	0.140	99.9	0.00	0.315
D88	Sample	0.00	0.00	99.3	0.680	0.299
D90	Sample	0.00	85.4	14.6	0.00	19.9
D92	Sample	0.00	0.00	99.7	0.346	0.3
D94	Sample	0.00	0.0153	100.0	0.00	0.31
D96	Sample	0.00	0.00	100	0.00	0.22
D98	Sample	0.00	0.00	99.7	0.345	0.25
D100	Sample	0.00	0.00	100	0.00	0.349
D102	Sample	0.00	0.267	98.7	0.997	0.399
D104	Sample	0.00	0.219	99.8	0.00	0.307
D106	Sample	0.00	0.274	99.7	0.00	0.35
D108	Sample	0.00	45.6	54.4	0.00	0.56
D110	Sample	0.00	0.00	99.6	0.353	0.308
D114	Sample	0.00	0.607	99.4	0.00	0.309
D116	Sample	0.00	72.2	27.5	0.384	5.01
D118	Sample	0.00	0.00	94.8	5.15	0.22
D120	Sample	0.00	0.00	100	0.00	0.32
D122	Particle Count	4.00	93.0	3.00	0.00	30.0



Site	Sample taken	Percentage				D <sub>50</sub> in millimeters*
		Bedrock/Hard Clay/Cemented Sands/Boulders/Cobbles > 64.0 mm	Gravel 2.00 - 64.0 mm	Sand 0.063 - 1.99 mm	Silt and clay < 0.063 mm	
D124	Sample	0.00	0.331	99.7	0.00	0.3
D126	Sample	0.00	54.0	45.7	0.312	3.1
D128	Sample	0.00	0.0304	100	0.00	0.34
E130	Sample	0.00	26.5	73.5	0.00	0.34
E132	Particle Count	0.00	99.0	1.00	0.00	16.0
E134	Particle Count	3.00	97.0	0.00	0.00	17.0
E136	Sample	0.00	37.5	62.5	0.00	0.43
E138	Particle Count	0.00	100	0.00	0.00	19.0
E140	Sample	0.00	24.5	75.5	0.00	0.525
E142	-	100% Bedrock	0.00	0.00	0.00	5000
E144	-	100% Bedrock	0.00	0.00	0.00	5000
E146	-	100% Bedrock	0.00	0.00	0.00	5000
E148	-	100	0.00	0.00	0.00	-
E150	-	100	0.00	0.00	0.00	-
E152	-	100% Bedrock	0.00	0.00	0.00	5000
E154	Sample	0.00	1.71	97.6	0.657	0.31
E156	-	100% Bedrock	0.00	0.00	0.00	5000
E157.5	-	100% Bedrock	0.00	0.00	0.00	5000
F158	-	100% Bedrock	0.00	0.00	0.00	5000
F160	-	100% Bedrock	0.00	0.00	0.00	5000
F162	-	100% Bedrock	0.00	0.00	0.00	5000
F164	-	100	0.00	0.00	0.00	-
F166	Sample	0.00	0.00	100	0.00	0.517
F168	Sample	0.00	0.00	100	0.00	0.517
F170	Sample	0.00	0.648	99.4	0.00	0.312
F172	Sample	0.00	52.5	47.4	0.163	4.76

\* Where no sample was taken the following D<sub>50</sub> values were calculated from upper and lower class size boundaries:

Bedrock; 5000 mm

Gravel; 11.3 mm

Gravel/sand; 5.83 mm

Sand; 0.355 mm



## **APPENDIX D**

**Rapid Geomorphic Assessment (RGA) data from the Buttahatchee River main stem and several tributaries.**



Appendix D – Rapid Geomorphic Assessments (RGAs) along the Buttahatchee River and Tributaries.

State	Site number	River kilometer	Top width in meters	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Streambank erosion		Streambank instability		Woody vegetative cover		Bank accretion		Channel stability index
									Left	Right	Left	Right	Left	Right	Left	Right	
MS	F172	172	16.8	V	Gravel/Sand	No	76-100%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	51-75%	51-75%	26-50%	15
MS	F170	170	24.8	V	Gravel/Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	51-75%	26-50%	51-75%	16
MS	F168	168	23.4	V	Gravel/Sand	No	26-50%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	51-75%	26-50%	26-50%	18.5
MS	F166	166	23.6	V	Sand	No	76-100%	0-10%	Fluvial	Mass Wasting	11-25%	26-50%	76-100%	51-75%	76-100%	51-75%	12.5
MS	F164	164	19.8	V	Boulder/Cobble	No	51-75%	11-25%	Mass Wasting	Fluvial	26-50%	11-25%	51-75%	76-100%	51-75%	51-75%	13
MS	F162	162	17.3	VI	Bedrock	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	76-100%	51-75%	3
MS	F160	160	21.7	V	Bedrock	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	26-50%	26-50%	51-75%	14
MS	F158	158	25.6	V	Bedrock	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	51-75%	51-75%	51-75%	13
MS	E157.5	157.5	15.5	VI	Bedrock	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	76-100%	51-75%	4
MS	E156	156	23.2	VI	Bedrock	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	76-100%	51-75%	51-75%	4
MS	E154	154	23.5	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	51-75%	11-25%	26-50%	18
MS	E152	152	27.7	VI	Bedrock	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	51-75%	51-75%	3.5
MS	E150	150	24.5	VI	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	3.5
MS	E148	148	34.6	VI	Boulder/Cobble	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	3.5
MS	E146	146	33.8	VI	Bedrock	No	76-100%	0-10%	None	None	0-10%	0-10%	51-75%	51-75%	76-100%	76-100%	3.5
MS	E144	144	28.9	VI	Bedrock	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	76-100%	51-75%	4.5
MS	E142	142	35.7	VI	Bedrock	No	76-100%	11-25%	None	None	0-10%	0-10%	76-100%	76-100%	51-75%	51-75%	4.5
MS	E140	140	24.1	V	Sand	No	76-100%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	26-50%	51-75%	26-50%	16.5
MS	E138	138	31.2	V	Gravel	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	51-75%	51-75%	51-75%	15.5
MS	E136	136	33.6	V	Sand	No	26-50%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	26-50%	51-75%	51-75%	18.5
MS	E134	134	35.9	V	Gravel	No	26-50%	0-10%	Mass Wasting	Mass Wasting	26-50%	51-75%	26-50%	26-50%	51-75%	26-50%	18
MS	E132	132	34.6	V	Gravel	No	76-100%	0-10%	None	Mass Wasting	11-25%	26-50%	76-100%	51-75%	76-100%	51-75%	10.5
MS	E130	130	42.2	V	Sand	No	76-100%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	26-50%	51-75%	26-50%	16.5
MS	E128	128	34.6	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	26-50%	26-50%	26-50%	18.5
MS	D126	126	31.3	V	Sand	No	51-75%	0-10%	Mass Wasting	None	51-75%	11-25%	26-50%	51-75%	26-50%	76-100%	14.5
MS	D124	124	31.8	V	Sand	No	76-100%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	51-75%	51-75%	51-75%	16
MS	D122	122	47.0	V	Gravel	No	51-75%	11-25%	Mass Wasting	None	26-50%	11-25%	26-50%	51-75%	51-75%	51-75%	14
MS	D120	120	43.2	V	Sand	No	51-75%	0-10%	Mass Wasting	None	51-75%	11-25%	26-50%	76-100%	51-75%	51-75%	14
MS	D118	118	38.1	V	Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	26-50%	51-75%	11-25%	76-100%	16
MS	D118	118	39.1	V	Sand	No	51-75%	0-10%	Mass Wasting	None	51-75%	11-25%	26-50%	76-100%	26-50%	51-75%	14.5
MS	D114	114	55.7	V	Sand	No	51-75%	0-10%	None	Mass Wasting	0-10%	26-50%	76-100%	26-50%	51-75%	26-50%	13.5
MS	D112	112	32.0	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	76-100%	26-50%	26-50%	51-75%	11-25%	19
MS	D110	110	38.3	V	Sand	No	51-75%	0-10%	Mass Wasting	None	51-75%	11-25%	51-75%	76-100%	51-75%	51-75%	13.5
MS	D108	108	53.2	V	Gravel/Sand	No	26-50%	0-10%	Mass Wasting	Fluvial	76-100%	11-25%	26-50%	51-75%	26-50%	51-75%	17
MS	D106	106	45.5	V	Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	76-100%	11-25%	26-50%	51-75%	11-25%	76-100%	16.5
MS	D104	104	31.2	V	Sand	No	26-50%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	51-75%	76-100%	51-75%	51-75%	15
MS	D102	102	27.9	V	Sand	No	26-50%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	51-75%	51-75%	26-50%	51-75%	16.5
MS	D100	100	26.5	V	Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	26-50%	51-75%	51-75%	51-75%	15.5
MS	D98	98	21.4	V	Sand	No	26-50%	26-50%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	51-75%	51-75%	51-75%	20
MS	D96	96	22.5	V	Sand	No	26-50%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	51-75%	51-75%	26-50%	17.5



State	Site number	River kilometer	Top width in meters	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Streambank erosion		Streambank instability		Woody vegetative cover		Bank accretion		Channel stability index
									Left	Right	Left	Right	Left	Right	Left	Right	
MS	D94	94	25.1	V	Sand	No	26-50%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	26-50%	26-50%	51-75%	18.5
MS	D92	92	24.3	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	26-50%	26-50%	51-75%	26-50%	51-75%	17
MS	D90	90	31.6	V	Gravel	No	26-50%	11-25%	Mass Wasting	Mass Wasting	76-100%	51-75%	26-50%	26-50%	11-25%	51-75%	20.5
MS	D88	88	35.7	V	Sand	No	26-50%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	51-75%	26-50%	51-75%	18.5
MS	D87	87	0.0	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	51-75%	51-75%	26-50%	51-75%	26-50%	17.5
MS	C85	85	26.5	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	51-75%	51-75%	26-50%	51-75%	26-50%	17.5
MS	C83	83	19.4	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	51-75%	51-75%	26-50%	51-75%	51-75%	17
MS	C81	81	21.6	V	Gravel	No	51-75%	0-10%	Mass Wasting	Mass Wasting	26-50%	51-75%	51-75%	51-75%	26-50%	51-75%	16
MS	C79	79	30.9	V	Sand	No	51-75%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	51-75%	51-75%	51-75%	51-75%	16.5
MS	C77	77	33.6	V	Sand	No	51-75%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	51-75%	26-50%	51-75%	26-50%	16
MS	C75	75	26.8	V	Sand	No	76-100%	0-10%	Mass Wasting	None	51-75%	0-10%	51-75%	76-100%	26-50%	76-100%	12
MS	C73	73	26.8	V	Sand	No	51-75%	0-10%	None	Mass Wasting	0-10%	26-50%	51-75%	26-50%	51-75%	26-50%	14
MS	C71	71	20.6	V	Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	51-75%	76-100%	51-75%	76-100%	14
MS	C69	69	22.3	VI	Sand	No	76-100%	0-10%	Fluvial	None	11-25%	0-10%	76-100%	76-100%	51-75%	51-75%	8
MS	C67	67	21.8	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	10
MS	C65	65	23.5	V	Gravel	No	76-100%	0-10%	Mass Wasting	Mass Wasting	51-75%	26-50%	51-75%	51-75%	51-75%	51-75%	14.5
MS	C63	63	28.0	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	51-75%	76-100%	26-50%	76-100%	13.5
MS	C60	60	30.0	V	Sand	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	11
MS	B58	58	29.2	V	Gravel/Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	26-50%	51-75%	26-50%	51-75%	15.5
MS	B56	56	29.2	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	26-50%	51-75%	11-25%	51-75%	15.5
MS	B54	54	41.7	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	26-50%	51-75%	11-25%	51-75%	15.5
MS	B52	52	43.8	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	11-25%	51-75%	11-25%	26-50%	16.5
MS	B50	50	35.1	V	Gravel	No	76-100%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	26-50%	51-75%	26-50%	76-100%	13
MS	B48	48	41.4	V	Gravel	Yes	51-75%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	11-25%	51-75%	76-100%	26-50%	14
MS	B46	46	36.1	V	Gravel	No	76-100%	0-10%	Mass Wasting	Fluvial	51-75%	11-25%	11-25%	51-75%	11-25%	26-50%	15.5
MS	B44	44	41.3	V	Gravel	No	26-50%	11-25%	Mass Wasting	Mass Wasting	51-75%	26-50%	26-50%	51-75%	26-50%	51-75%	18.5
MS	B42	42	37.2	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	51-75%	11-25%	76-100%	13.5
MS	B41	41	54.0	V	Gravel	No	51-75%	0-10%	Fluvial	Mass Wasting	11-25%	51-75%	26-50%	51-75%	51-75%	11-25%	15.5
MS	B40	38	49.1	V	Gravel	No	76-100%	0-10%	Fluvial	Mass Wasting	11-25%	26-50%	76-100%	51-75%	51-75%	26-50%	12.5
MS	B40	39	64.5	V	Gravel	No	76-100%	0-10%	None	Mass Wasting	0-10%	51-75%	51-75%	11-25%	51-75%	11-25%	13.5
MS	B36	38	42.1	V	Gravel	No	51-75%	0-10%	None	Mass Wasting	0-10%	51-75%	51-75%	26-50%	51-75%	26-50%	13.5
MS	B37	37	53.1	V	Gravel	No	76-100%	11-25%	Mass Wasting	Mass Wasting	26-50%	26-50%	51-75%	51-75%	51-75%	11-25%	16
MS	B36	38	28.4	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	26-50%	51-75%	11
MS	B35	38	43.2	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	26-50%	76-100%	10.5
MS	A33	38	53.4	V	Gravel	No	76-100%	0-10%	None	Mass Wasting	11-25%	26-50%	26-50%	51-75%	26-50%	51-75%	12.5
MS	A33	38	50.0	VI	Gravel	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	51-75%	51-75%	51-75%	7
MS	A32	32	41.7	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	26-50%	51-75%	26-50%	51-75%	11
MS	A31	31	64.8	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	0-10%	51-75%	51-75%	26-50%	76-100%	11
MS	A30	30	53.4	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	51-75%	26-50%	76-100%	5.5
MS	A29	29	59.7	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	26-50%	76-100%	12
MS	A28	28	56.6	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	51-75%	51-75%	76-100%	5.5
MS	A27	27	50.1	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	51-75%	51-75%	76-100%	



State	Site number	River kilometer	Top width in meters	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Streambank erosion		Streambank instability		Woody vegetative cover		Bank accretion		Channel stability index
									Left	Right	Left	Right	Left	Right	Left	Right	
MS	A26	26	64.1	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	26-50%	26-50%	6.5
MS	A25	25	59.8	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	11-25%	26-50%	7
MS	A24	24	50.9	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	26-50%	11-25%	7
MS	A23	23	75.7	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	26-50%	51-75%	12
MS	A22	22	58.1	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	51-75%	11.5
MS	A21	21	50.9	V	Gravel	No	76-100%	0-10%	Fluvial	None	26-50%	0-10%	51-75%	76-100%	51-75%	51-75%	9.5
MS	A20	20	52.7	VI	Gravel	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	51-75%	51-75%	5.5
MS	A19	19	52.4	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	11
MS	A18	18	33.6	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	76-100%	11-25%	76-100%	13
MS	A17	17	39.8	VI	Gravel	No	76-100%	0-10%	None	None	11-25%	0-10%	51-75%	51-75%	51-75%	76-100%	6.5
MS	A16	16	No channel	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	51-75%	0-10%	26-50%	76-100%	51-75%	76-100%	12
MS	A15	15	39.3	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	51-75%	51-75%	51-75%	11
MS	A14	14	No channel	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	76-100%	26-50%	76-100%	11.5
MS	A13	13	27.1	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	76-100%	11-25%	76-100%	13
MS	A12	12	46.4	V	Gravel	No	26-50%	0-10%	Mass Wasting	None	76-100%	0-10%	11-25%	51-75%	0-10%	76-100%	16
MS	A11	11	63.0	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	51-75%	11-25%	76-100%	13.5
MS	A10	10	-	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	51-75%	0-10%	11-25%	26-50%	26-50%	76-100%	14
MS	A9	9	36.9	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	26-50%	51-75%	76-100%	11
MS	A8	8	59.3	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	11-25%	26-50%	51-75%	51-75%	51-75%	12.5
MS	A7	7	57.1	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	51-75%	0-10%	26-50%	26-50%	26-50%	26-50%	14.5
MS	A6	6	37.2	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	76-100%	0-10%	11-25%	51-75%	11-25%	76-100%	14.5
MS	A5	5	57.2	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	51-75%	0-10%	11-25%	51-75%	11-25%	76-100%	14
MS	A4	4	76.8	V	Gravel	No	51-75%	11-25%	Mass Wasting	None	51-75%	0-10%	26-50%	26-50%	11-25%	76-100%	15
MS	A4	3	52.3	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	11-25%	26-50%	51-75%	26-50%	51-75%	13
MS	A2	2	57.5	V	Gravel	No	76-100%	11-25%	Mass Wasting	None	26-50%	0-10%	26-50%	51-75%	51-75%	76-100%	12
MS	A1	1	68.9	V	Gravel	No	76-100%	0-10%	Mass Wasting	None	51-75%	0-10%	26-50%	51-75%	26-50%	76-100%	12
MS	A0	0	Waterway	-	-	-	-	-	-	-	-	-	-	-	-	-	-



## Rapid Geomorphic Assessments (RGAs) carried out on Tributaries to the Buttahatchee River.

State	Site number	Stage of channel evolution	Bed material	Bed or bank protection	Incision	Constriction	Streambank erosion		Streambank instability		Woody vegetative cover		Bank accretion		Channel stability index
							Left	Right	Left	Right	Left	Right	Left	Right	
MS	Cantrell Mill 01	V1	Gravel	No	76-100%	0-10%	None	Fluvial	11-25%	0-10%	51-75%	76-100%	51-75%	51-75%	7.5
MS	Camp Brenah 01	V1	Sand	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	76-100%	51-75%	7
MS	Roy Mill Branch 01	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	26-50%	11-25%	51-75%	51-75%	51-75%	51-75%	13.5
MS	Running Slough	V1	Gravel	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	51-75%	26-50%	7
MS	Martin Road	V1	Gravel	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	51-75%	76-100%	7.5
MS	OWR01	V	Hard Clay	No	26-50%	0-10%	Mass Wasting	None	26-50%	0-10%	26-50%	51-75%	26-50%	26-50%	13.5
MS	OWR03	V1	Gravel	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	51-75%	76-100%	76-100%	6.5
MS	Bluff Creek	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	11
MS	OWR04	V1	Gravel	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	51-75%	51-75%	8
MS	Honnell Mill Creek	V1	Gravel/Sand	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	51-75%	51-75%	8.5
MS	Alsop Creek	V1	Sand	No	51-75%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	51-75%	76-100%	8.5
MS	Sipsey Creek 01	V1	Gravel/Sand	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	26-50%	26-50%	51-75%	51-75%	11
MS	Sipsey Creek 02	V1	Gravel	No	51-75%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	51-75%	76-100%	9
AL	Sipsey Creek 03	V1	Sand	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	51-75%	51-75%	76-100%	9
AL	Sipsey Creek 04	V1	Sand	No	76-100%	11-25%	Mass Wasting	None	11-25%	0-10%	51-75%	76-100%	51-75%	76-100%	10
AL	Sipsey Creek 05	V	Gravel	No	76-100%	0-10%	None	Fluvial	0-10%	11-25%	51-75%	76-100%	76-100%	76-100%	8
AL	Sipsey Creek 06	V1	Sand	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	76-100%	76-100%	7
AL	Sipsey Creek 07	V1	Sand	No	76-100%	0-10%	Fluvial	Fluvial	26-50%	0-10%	51-75%	76-100%	51-75%	51-75%	10
AL	Pine Springs Trib 1	V1	Gravel	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	76-100%	76-100%	6
AL	Pine Springs Trib 2	V1	Gravel	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	6.5
AL	Loggains Branch	V	Gravel/Sand	No	51-75%	0-10%	Mass Wasting	Fluvial	26-50%	0-10%	51-75%	51-75%	26-50%	51-75%	14
AL	Mill Creek	V1	Gravel/Sand	No	76-100%	0-10%	Fluvial	Fluvial	0-10%	0-10%	51-75%	76-100%	76-100%	76-100%	7.5
AL	Mayfield Branch	V1	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	76-100%	76-100%	5.5
AL	BVR01	V	Gravel	No	76-100%	0-10%	Mass Wasting	Fluvial	26-50%	0-10%	51-75%	76-100%	51-75%	51-75%	11.5
AL	BVR02	V	Sand	No	76-100%	0-10%	Mass Wasting	None	11-25%	0-10%	76-100%	51-75%	51-75%	51-75%	11
AL	BVR03	V	Sand	No	76-100%	0-10%	Mass Wasting	Fluvial	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	12
AL	WTK01	V1	Gravel/Sand	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	76-100%	76-100%	51-75%	51-75%	7
AL	PGY01	V1	Sand	No	76-100%	0-10%	None	Fluvial	0-10%	0-10%	76-100%	76-100%	51-75%	76-100%	7
AL	BVR04	V	Gravel	No	51-75%	0-10%	Mass Wasting	Fluvial	26-50%	0-10%	26-50%	51-75%	51-75%	51-75%	13.5
AL	BVR05	V	Gravel	No	51-75%	0-10%	Mass Wasting	None	26-50%	0-10%	51-75%	76-100%	51-75%	76-100%	11
AL	BDT01	V1	Gravel/Sand	No	76-100%	0-10%	Fluvial	None	0-10%	0-10%	51-75%	76-100%	76-100%	51-75%	7
AL	BNS01	V1	Sand	No	76-100%	0-10%	None	None	0-10%	0-10%	76-100%	76-100%	51-75%	76-100%	6



## **APPENDIX E**

**APPENDIX E – Locations of Rapid Geomorphic Assessments (RGAs) carried out on the Buttahatchee River and select Tributaries.**



Locations of sites on the Buttahatchee River

Site	ZoneNAD83	East	North	Elevation
A1	16S	361454	3725782	135.00
A10	16S	367382	3726674	188.00
A11	16S	368082	3726915	199.00
A12	16S	368400	3726436	195.00
A13	16S	368653	3727067	195.00
A14	16S	369118	3726853	203.00
A15	16S	369438	3727030	210.00
A16	16S	369838	3727451	210.00
A17	16S	370092	3727677	203.00
A18	16S	370598	3727931	210.00
A19	16S	370397	3728701	213.00
A2	16S	362050	3725730	143.00
A20	16S	370783	3729246	210.00
A21	16S	371503	3729022	220.00
A22	16S	371594	3728577	217.00
A23	16S	372424	3728136	210.00
A24	16S	372963	3728467	213.00
A25	16S	373702	3728921	192.00
A26	16S	374383	3729592	188.00
A27	16S	375214	3730114	195.00
A28	16S	375592	3730787	195.00
A29	16S	375970	3731527	198.00
A3	16S	362806	3726136	162.00
A30	16S	376747	3731898	198.00
A31	16S	377039	3732639	173.00
A32	16S	376973	3733298	199.00
A33	16S	376927	3733899	195.00
A34	16S	377253	3734740	199.00
A4	16S	363508	3726262	162.00
A5	16S	364382	3726093	162.00
A6	16S	365001	3725829	173.00
A7	16S	365587	3726538	169.00
A8	16S	365972	3726642	165.00
A9	16S	366722	3726315	165.00
B35	16S	377744	3734780	195.00
B36	16S	377517	3735455	195.00
B37	16S	377687	3736063	199.00
B38	16S	378204	3736343	210.00
B39	16S	378468	3737155	195.00
B40	16S	378420	3738031	199.00
B41	16S	378192	3738870	214.00
B42	16S	377945	3739378	210.00
B44	16S	378823	3740455	210.00
B46	16S	378973	3742196	221.00
B48	16S	379129	3743298	225.00
B50	16S	378519	3744653	214.00
B52	16S	378022	3745633	250.00
B54	16S	379151	3746183	217.00
B56	16S	379993	3747067	239.00
B58	16S	380581	3748316	236.00
C60	16S	380889	3749693	259.00
C63	16S	381804	3751292	262.00
C65	16S	382611	3751871	266.00
C67	16S	383719	3751606	269.00

Site	ZoneNAD83	East	North	Elevation
C69	16S	384938	3751514	269.00
C71	16S	385941	3751090	269.00
C73	16S	387462	3751051	277.00
C75	16S	388839	3750989	277.00
C77	16S	389842	3751419	277.00
C79	16S	390878	3751747	281.00
C81	16S	391478	3752553	281.00
C83	16S	392062	3753027	288.00
C85	16S	393302	3753503	288.00
D100	16S	400645	3758264	310.00
D102	16S	401641	3759703	311.00
D104	16S	402587	3761073	327.00
D106	16S	402410	3762426	330.00
D108	16S	403016	3763568	333.00
D110	16S	402719	3764580	329.00
D112	16S	402751	3765927	329.00
D114	16S	404094	3766993	329.00
D116	16S	405865	3767842	344.00
D118	16S	406781	3769156	344.00
D120	16S	406818	3770337	348.00
D122	16S	406209	3771537	344.00
D124	16S	406772	3773368	345.00
D126	16S	407904	3773333	374.00
D128	16S	408696	3774431	370.00
D87	16S	394140	3753996	295.00
D88	16S	394861	3754391	299.00
D90	16S	396058	3755668	299.00
D92	16S	397462	3755980	303.00
D94	16S	399020	3755956	303.00
D96	16S	399560	3756830	307.00
D98	16S	400196	3757762	311.00
E130	16S	409572	3774101	358.00
E132	16S	409046	3775797	377.00
E134	16S	409922	3777496	383.00
E136	16S	410509	3779195	401.00
E138	16S	411346	3779801	433.00
E140	16S	413194	3780087	434.00
E142	16S	414659	3779101	411.00
E144	16S	415804	3778135	448.00
E146	16S	417774	3778450	470.00
E148	16S	418735	3778320	449.00
E150	16S	420170	3777145	461.00
E152	16S	421249	3776493	501.00
E154	16S	422146	3775885	481.00
E156	16S	423243	3777072	497.00
E157.5	16S	423845	3777575	497.00
F158	16S	424651	3777138	501.00
F160	16S	425235	3775773	501.00
F162	16S	426400	3775987	516.00
F164	16S	427383	3776861	519.00
F166	16S	428705	3776238	530.00
F168	16S	429901	3776293	526.00
F170	16S	430906	3775866	549.00
F172	16S	432285	3775176	572.00



## Locations of sites on Buttahatchee River Tributaries

Site	ZoneNAD83	East	North	Elevation
ALS1	16S	380038	3740817	234
BDT1	16S	395462	3777701	420
BLFCRK	16S	378089	3732016	257
BSN1	16S	395711	3777486	421
BVR01	16S	400334	3753853	318
BVR02	16S	405431	3755515	351
BVR03	16S	410233	3757651	397
BVR04	16S	413069	3758959	420
BVR05	16S	414025	3761573	436
HMC01	16S	378434	3734503	230
LB01	16S	397176	3758024	334
MAB01	16S	403723	3767366	367
MC01	16S	399655	3761599	354
MTNRD	16S	375580	3729362	230
OWR01	16S	376319	3729158	263
OWR03	16S	377660	3731086	263
OWRD04	16S	378025	3733392	230
PGY01	16S	414110	3758391	428
PS01	16S	393599	3756592	331
PS02	16S	394028	3754460	302
REW	16S	380069	3742046	277
RMB01	16S	403770	3762143	363
RNNSL	16S	373508	3730267	214
S1	16S	381226	3751408	221
S2	16S	381005	3751195	245
S3	16S	380621	3751122	260
S4	16S	380564	3750792	260
S5	16S	380453	3750634	259
S6	16S	380383	3750487	277
S7	16S	380428	3750266	270
SIP1	16S	382563	3753739	269
SIP2	16S	384130	3757293	289
SIP3	16S	389091	3764821	339
SIP4	16S	391055	3765803	348
SIP5	16S	394316	3769665	371
SIP6	16S	394673	3774206	395
SIP7	16S	395123	3777899	420





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